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The Servitization Transformation Path of Manufacturing Enterprises under the Background of the Digital Economy

ZHANG Kaizhi

Doctor of Management

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University of Évora
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May, 2025

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Marketing, Operations and General Management Department

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The Servitization Transformation Path of Manufacturing Enterprises under the Background of the Digital Economy

ZHANG Kaizhi

Declaration

I declare that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university and that to the best of my knowledge it does not contain any material previously published or written by another person except where due reference is made in the text.

Signed: 张恺之 Zhang Kaizhi Date:2025.6.30

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Abstract

To achieve the new technological revolution and escape the trap of low value production, it is inevitable to accelerate production servitization in the digital economy. In this thesis, a transformation mechanism composed of technological, organizational and environmental factors is built based on the resources-based view, dynamic capabilities, and resource dependence theories. Based on a sample of 102 companies from Shandong manufacturers in the year 2023, using a mixed methods approach combining OLS regression and fsQCA, to explore the causal mechanisms and paths of servitization, this study analyzes the multiple-factors effects on servitization, conditional configurations, and cases. The study contributes to theoretical knowledge and gives empirical findings to policy makers and managers.

Through a comprehensive analysis of influencing factors, conditional configurations, and causal processes, this study has identified the causal chain of "influencing factors - conditional configurations - development models" in manufacturing servitization. First, it concludes that servitization of manufacturing does not rely on the driving force of a single factor but is the result of the interaction of six factors — digital infrastructure, technological innovation, organizational structure, human resources, government support, and industry competition — all exert a significant positive promotional effect on this transformation. Among these factors, technological innovation provides a strong driving force for the servitization transformation of manufacturing, while human resources are an indispensable element for achieving high-level servitization transformation. Second, the differentiated development paths of manufacturing servitization can be categorized into three synergistic models: the "organization-environment" and "technology-organization" dual synergy models, and the "technology-organization-environment" triple synergy model. Finally, technological and environmental factors cannot function independently of organizational elements. In the process of manufacturing servitization, organizational elements serve as foundational and necessary conditions, technological elements act as driving forces, and the external environment impacts resource allocation and directional guidance, collectively promoting the advancement of manufacturing servitization.

Keywords: Manufacturing, Servitization, Technology, Organization, Environment, Configuration Study

JEL: M84; O35

Resumo

Para alcançar a nova revolução tecnológica e escapar da armadilha da produção de baixo valor, é inevitável acelerar a servitização da produção na economia digital. Esta tese desenvolve um mecanismo de transformação composto por fatores tecnológicos, organizacionais e ambientais com base nas teorias RBV, das capacidades dinâmicas e da dependência de recursos. Utilizando uma amostra de 102 empresas industriais de Shandong recolhe dados relativos a 2023, e utiliza uma abordagem de métodos mistos de análise de dados que combina modelos de regressão OLS e fsQCA, para explorar os mecanismos causais e os caminhos da servitização, este estudo analisa os efeitos de múltiplos fatores na servitização, configurações condicionais e casos. O estudo contribui para o conhecimento teórico e fornece conclusões empíricas aos decisores políticos e gestores.

Através de uma análise abrangente dos fatores de influência, configurações condicionais e processos causais, este estudo identifica a cadeia causal de "fatores de influência → configurações condicionais → modelos de desenvolvimento" na servitização da indústria transformadora. Conclui, primeiro, que a servitização da indústria transformadora não depende da força motriz de um único fator, mas é o resultado da interação de seis fatores — infraestrutura digital, inovação tecnológica, estrutura organizacional, recursos humanos, apoio governamental e concorrência industrial — todos exercendo um efeito promocional positivo significativo nesta transformação. Entre esses fatores, a inovação tecnológica atua como uma forte força motriz para a transformação da servitização, enquanto os recursos humanos são um elemento indispensável para alcançar uma transformação de servitização de alto nível. Segundo, os caminhos de desenvolvimento diferenciados da servitização da indústria transformadora podem ser categorizados em três modelos sinérgicos: os modelos de sinergia dupla "organização-ambiente" e "tecnologia-organização", e o modelo de sinergia tripla "tecnologia-organização-ambiente". Por fim, os fatores tecnológicos e ambientais não podem funcionar independentemente dos elementos organizacionais. No processo de servitização, os elementos organizacionais servem como condições fundamentais e necessárias, os elementos tecnológicos atuam como forças motrizes e o ambiente externo impacta a alocação de recursos e orientação direcional, promovendo coletivamente o avanço da servitização da indústria transformadora.

Palavras-chave: Indústria, Servitização, Tecnologia, Organização, Ambiente, Estudo de Configuração

JEL: M84; O35

摘 要

为了实现新的技术革命并摆脱低价值陷阱，加速数字经济中的生产服务化是不可避免的。本研究基于资源基础理论（RBV）、动态能力理论和资源依赖理论，构建了一个由技术、组织和环境因素组成的转型机制。基于 2023 个样本（102 家山东制造企业）及 OLS 回归、fsQCA 方法，本研究探讨了服务化转型中的因果机制与路径，分析了单一因素对服务化的影响、条件配置及案例。研究成果既丰富了理论知识，也为政策制定者和管理者提供了实证依据。

通过对影响因素、条件配置和因果过程的综合分析，本研究系统地识别了制造业服务化转型中“影响因素→条件配置→发展模式”的因果链。结论如下：首先，制造业的服务化转型并非依赖单一因素的驱动，而是多种因素相互作用的结果。跨越三个维度的六个要素——数字基础设施、技术创新、组织结构、人力资源、政府支持和行业竞争——均发挥重要作用。其中，技术创新为服务化转型提供强大驱动力，而人力资源是实现高水平服务化的必要条件。其次，制造业服务化发展的差异化路径可归纳为三种协同模型：组织-环境双协同模型、技术-组织双协同模型，以及技术-组织-环境三协同模型。最后，技术和环境因素无法独立于组织要素而发挥作用。在制造业服务化过程中，组织要素作为基础性和必要条件，技术要素作为驱动力，而外部环境在资源配置和方向性指导方面，共同推动制造业服务化的发展。

关键词：制造业，服务化，技术，组织，环境，组态研究

JEL: M84; O35

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List of Abbreviations

AI: Artificial Intelligence

A-share: Chinese domestic stock market listing

CE-FDH: Ceiling Envelopment - Free Disposal Hull

CR-FDH: Ceiling Regression - Free Disposal Hull

FsQCA: fuzzy-set Qualitative Comparative Analysis

csQCA: Crisp-set Qualitative Comparative Analysis

DCT: Dynamic Capabilities Theory

DI: Digital Infrastructure

GDP: Gross Domestic Product

GS: Government Support

GVC: Global Value Chain

HHI: Herfindahl-Hirschman Index

HR: Human Resources

IC: Industry Competition

IoT: Internet of Things

mvQCA: Multi-value Qualitative Comparative Analysis

NCA: Necessary Condition Analysis

OLS: Ordinary Least Squares

PSS: Product-Service System

RBV: Resource-Based View

RDT: Resource Dependence Theory

R&D: Research and Development

SDL: Service-Dominant Logic

SMEs: Small and Medium-Sized Enterprises

ST/*ST: Special Treatment (listed companies with financial difficulties)

TI: Technological Innovation

TOE: Technology-Organization-Environment

VIF: Variance Inflation Factor

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Chapter 1: Introduction

1.1 Research background

Against the backdrop of continued global economic sluggishness, rising international trade protectionism, and increasing resource and environmental constraints, promoting the servitization transformation of manufacturing has become an important strategic choice for global manufacturers to cope with a complex environment and achieve sustainable development (J. Zhou, 2024). During this profound transformation of global manufacturing, developed countries, relying on their century-long accumulation of industrial technologies, are vigorously promoting digital and intelligent transformation to strengthen their dominant position in the global manufacturing system through servitization. Emerging economies, though experiencing rapid growth in manufacturing scale, generally face the structural dilemma of being “large but not strong,” suffering from low value-added, insufficient technological content, and limited innovation capacity (Cao & Chen, 2024). Meanwhile, the slowdown of globalization, the shock of the COVID-19 pandemic, and the reindustrialization strategies of major economies have further intensified the survival and competitive pressures faced by manufacturing enterprises in emerging economies within global value chains (Q. Chen et al., 2019).

Manufacturing servitization, by integrating "manufacturing + services", offers comprehensive solutions to customers. It not only effectively enhances product value and enterprise competitiveness (J. Zhou, 2024) but also optimizes resource allocation and reduces operational costs, thereby creating greater potential for green transformation and sustainable global economic growth. Furthermore, the servitization transformation provides a practical path for manufacturers to climb up the global value chain and escape from low-end positioning (Vargo & Lusch, 2004). As such, manufacturing servitization has become a universal choice for enterprises worldwide to respond to complex challenges. Through servitization, enterprises can extend the value chain, improve market responsiveness, and provide full-process service solutions throughout the product lifecycle, thereby increasing customer loyalty and global competitiveness.

In addition, the support of national policies has created an enabling environment for the development and integration of blockchain technology. Over the years, the Chinese government has released several policy documents that spur companies to actively explore the actual uses of blockchain technology. A good example is the 2021 "14th Five-Year National Informatization Plan," which specifically promoted the accelerated development and utilization of new technologies, including blockchain.

Despite this, small and medium enterprises face an array of hindrances in adopting blockchain technology, which range from high technological cost to the lack of expertise and poor understanding of the technology. Environmental uncertainty also raises the perceived risk SMEs attribute to the acceptance of new technology. Therefore, an exhaustive examination of the drivers behind the willingness of SMEs to use blockchain technology is conducted, which is essential in enhancing its use within these entities.

Under the digital economy, the rise of smart and digital technologies provides new technical support and perspectives for manufacturing servitization. Traditional extensive production models and low value-added products are gradually failing to meet the development demands of the digital economy era. Enterprises are urgently required to pursue servitization transformation to achieve high-quality development (C. Zhao, 2021). Leveraging big data, artificial intelligence, the Internet of Things, and other technologies, companies can more accurately identify customer needs, optimize production and service processes, and improve customer satisfaction through customized services. At the same time, the networking and platformization of digital technologies have driven profound changes in global production and consumption models. Manufacturers can not only deliver integrated service solutions through digital platforms but also expand market coverage and enhance the flexibility and diversity of service offerings through online-offline integration models.

As a major player in global manufacturing, China’s experience in servitization transformation holds significant reference value worldwide. Although China has become the largest manufacturing base globally, it still faces challenges such as being trapped at the low end of the value chain and lacking in quality and efficiency (Q. Huang & Yang, 2022). Servitization transformation provides a pathway for China to achieve structural upgrading and offers inspiration to the manufacturing sectors of other emerging economies. In the context of the fast-growing digital economy, promoting manufacturing servitization is not only an intrinsic demand for China’s high-quality development but also a critical strategic move for global enterprises to break through development bottlenecks and seize technological and market advantages. It contributes to building a greener, more efficient, and intelligent global manufacturing system, thereby injecting new momentum into the sustainable growth of the global economy (He & Qin, 2025).

As an important manufacturing base in China, Shandong Province's practices in promoting manufacturing servitization through the digital economy provide vivid examples for global manufacturers to explore transformation paths that integrate digitalization and servitization (L. Liu, 2008). A systematic study of Shandong's theory and practical experience in manufacturing servitization can serve as a reference for innovation and upgrading in China's manufacturing industry, while also offering valuable lessons for global manufacturing transformation and contributing to the building of a fairer and more sustainable global value chain system.

1.2 Research problem

In the context of global manufacturing upgrading, servitization has become a key strategic choice for enterprises to cope with market competition and achieve high-quality development. Particularly under the rapid development of the digital economy, the widespread adoption of digital technologies is profoundly changing the manufacturing industry's production methods, organizational forms, and business models, providing new momentum and perspectives for servitization transformation (Sui et al., 2025). However, in practice, manufacturers still face many challenges during this transition.

First, in terms of technology: although digital technologies play a crucial role in the servitization transformation (Gebauer et al., 2021), many manufacturers still lack technical capabilities, making it difficult to convert technological innovation into productivity and service capacity (J. Zhang et al., 2024).

Second, on the organizational level: successful transformation requires a comprehensive reform of organizational structure, management models, and human resources to adapt to the new demands of servitization. However, many firms remain entrenched in traditional product-oriented structures and fail to establish service-oriented organizational mechanisms, leading to low transformation efficiency despite technological upgrades (X. Zhang et al., 2024).

Third, in terms of the environment: external support for servitization remains inadequate, including insufficient policy incentives and underdeveloped industry ecosystems. Moreover, the elements of technology, organization, and environment must function synergistically during transformation. However, most enterprises face a mismatch or lack of coordination among these factors (J. Zhang et al., 2024).

Therefore, under the digital economy background, this study focuses on the "synergistic mechanism of technology, organization, and environment", exploring how these three factors interact to promote manufacturing servitization. Using Shandong Province as the research sample, the study combines theoretical construction, empirical analysis, and policy recommendations to reveal the drivers and pathways of servitization, providing both a theoretical foundation and practical guidance for enterprise upgrading, while also offering lessons for global manufacturing transformation.

1.3 Research questions

Amid the rapid development of the digital economy in Shandong Province, the servitization transformation of manufacturing has become a critical path for optimizing the economic structure and achieving high-quality development. As a major manufacturing province in China, Shandong has actively explored upgrading traditional manufacturing through servitization during the transition between old and new growth drivers, achieving notable progress (Y. Liu et al., 2023). This study aims to analyze the province's experience and identify key success factors to offer valuable references for other regions.

(1) The first question to aswer is what defines manufacturing servitization precisely in digital economy settings along with its key characteristics. Servitization involves more than continuing the production process. Servitization builds stronger ties between goods and services while improving innovation for greater value addition and servicing various consumer needs. For businesses to execute transformation successfully they must understand the core elements of servitization along with its digital economy contribution.

(2) The transformation process receives what influence from technology and organization and how much impact does the environment produce? Publicly listed manufacturers within Shandong form the research focus to investigate how digital technologies and organizational factors and external environment elements shape their servitization initiatives.

(3) What are the paths and core factors behind successful servitization transformation in Shandong Province? The study will investigate factors such as technological innovation, digital adoption, organizational efficiency, human capital investment, business environment, and government support. It will also explore how the alignment of these elements has driven Shandong's servitization progress and contributed to its high-quality economic development.

By analyzing these issues in depth, this research will reveal the general patterns of servitization transformation from a global perspective. It aims to provide theoretical guidance and practical inspiration for other manufacturing regions and nations, helping global manufacturing evolution.

1.4 Research purpose and significance

1.4.1 Research purpose

This study aims to explore the complex mechanisms and realization paths of manufacturing servitization transformation in the context of the digital economy. Through theoretical construction and empirical analysis, it seeks to reveal the synergistic effects and configuration paths of digital technologies, organizational structures, and external environments in driving servitization transformation, and to propose targeted recommendations based on the practical experience of manufacturing enterprises in Shandong Province. The specific research objectives are as follows: to construct a theoretical framework for manufacturing servitization transformation under the digital economy; to study the impact of six independent variables from the three dimensions of technology, organization, and environment on manufacturing servitization; to explore multiple paths of transformation; and to propose universal policy recommendations to help local governments and enterprises achieve high-quality development.

First, the goal is to construct a theoretical framework for manufacturing servitization transformation in the digital economy. Based on existing theories of manufacturing servitization and the development characteristics of the digital economy, the study proposes a Technology–Organization–Environment (TOE) framework of synergistic interaction. From a systems perspective, it analyzes how digital technologies, organizational optimization, and external support interact to drive transformation. Most existing studies focus on one single dimension, overlooking complex interrelations. This study, based on the TOE framework, explores how multi-dimensional and multi-factor elements affect servitization, thus filling that gap. It provides a better understanding of the complex influencing mechanisms and offers theoretical support for enterprise management practices during transformation.

Building on this framework, the second goal is to analyze how the six independent variables across the three TOE dimensions specifically affect manufacturing servitization. A quantitative approach is employed to test the actual impact of these variables, identifying the most significant drivers. Based on theoretical analysis, six variables are identified—enterprise digital infrastructure, technological innovation, organizational structure, management models, government policy, and market competition—and their roles in the transformation process are studied. This enriches the literature on the multi-factorial impacts on servitization and provides a new perspective for future academic research.

Third, the study explores multiple transformation paths of manufacturing servitization. By innovatively applying the qualitative comparative analysis (QCA) method, it analyzes the diverse and complex mechanisms behind the transformation in Shandong Province. QCA identifies key configuration paths and their characteristics under different conditions, revealing the complex logic and rules of transformation. This provides enterprises with a theoretical basis for choosing suitable transformation strategies in diverse environments.

Finally, using data from publicly listed manufacturing firms in Shandong—a leading province in manufacturing—this study proposes generalizable policies and managerial recommendations for servitization transformation. Based on theoretical and empirical results, it identifies key and common drivers, including digital infrastructure development, technological innovation, organizational optimization, talent factors, and external pressures and support. These insights provide practical strategies for enterprises and local governments, helping countries and regions achieve high-quality economic development.

1.4.2 Research significance

(1) Theoretical significance

In the process of global manufacturing transformation, servitization has become an important path to enhance the core competitiveness of enterprises, promote high-quality economic development and achieve sustainable development (Bustinza et al., 2015). As an important representative of China's manufacturing industry, Shandong Province's experience in manufacturing servitization is not only of reference significance for the transformation and upgrading of local economy, but also can provide guidance and reference for the innovation and transformation of global manufacturing industry (Y. Liu et al., 2023). This study focuses on the servitization path of manufacturing enterprises in Shandong Province, aiming to provide theoretical support and practical inspiration for regional economic development and governments, enterprises and academia.

First, it integrates the TOE theory with the concept of manufacturing servitization, systematically exploring the synergistic roles of technological innovation, organizational reform, and external environment in the transformation process. Most previous studies have focused on a single factor and overlooked multi-factor interactions. By incorporating all three dimensions, this study enriches the theoretical foundation of manufacturing servitization, especially under the growing importance of digital technologies. It shows how the interaction of these elements drives the transformation from production to services.

Second, from the digital economy perspective, this study examines servitization transformation pathways, providing theoretical guidance for digital technology-driven enterprise transformations. It reveals how digital and intelligent technologies optimize production and service processes, shifting manufacturing from traditional product-oriented models toward servitization models. Moreover, beyond traditional regression methods, this study uses QCA—combining qualitative and quantitative strengths—which overcomes the limitations of regression in revealing complex factor interactions. The study also proposes a typology based on QCA results, classifying configuration paths into distinct transformation models and analyzing typical cases, thereby deepening understanding of servitization.

(2) Practical significance

As global manufacturing transforms, servitization has become an essential path to enhance competitiveness, promote high-quality growth, and achieve sustainability. As a major manufacturing hub, Shandong's experience is not only valuable for local economic upgrading but also offers global insights and guidance (G. Han & Cai, 2025). This study focuses on the transformation paths of Shandong's manufacturing enterprises and aims to support regional development and offer practical strategies for policymakers, business leaders, and academics.

First, the transformation of manufacturing industry into service industry can effectively help global manufacturing enterprises break through the traditional "low added value lock-in" dilemma. Resource-intensive and labor-intensive manufacturing industries have long existed in many countries and regions, and the problems of low product added value and limited profit margins are particularly prominent. The transformation into service industry helps manufacturing enterprises move from simple product manufacturing to full life cycle service solution providers by extending the value chain, thereby improving product added value and enterprise market competitiveness (P. Yu & Gao, 2024).

This study takes Shandong Province as a case study and deeply explores the impact of technology, organization and environment on the servitization of manufacturing industry under the background of digital economy, so as to point out the direction for countries or regions to improve their position in the global industrial chain through servitization. Secondly, although the servitizatioin of manufacturing industry is a means to cope with global competition and enhance comprehensive competitiveness, it is difficult for countries to find the right development path in the process of servitization of manufacturing industry. There are often difficulties in coordinating and coordinating various factors such as technology, organization and environment, which leads to poor effect of servitizatioin and then changes the direction of transformation to "de-service" (Battisti et al., 2023). Combined with the specific practice of Shandong Province, this study analyzes the development path of enterprises in Shandong

Province that have successfully realized the servitization of manufacturing industry, so as to provide a feasible path reference for global manufacturing enterprises to successfully realize servitization driven by digital technology.

Finally, by analyzing transformation paths in Shandong, the study provides practical policy suggestions for governments. Servitization is a multi-factor process and cannot rely solely on technology. A supportive policy environment is equally important. This research offers scientific decision-making tools for governments and firms to navigate complex markets, aiding high-quality growth. Furthermore, manufacturing servitization supports global sustainability. It reduces resource consumption, lowers costs, and advances green manufacturing. By combining servitization with green technologies, enterprises can balance production, service, and environmental goals.

In conclusion, this study’s in-depth analysis of servitization drivers and pathways not only provides theoretical and practical guidance for manufacturers in Shandong but also offers a new theoretical framework and practical reference for global enterprises aiming for digital-age innovation and upgrading. It holds significant value for countries pursuing manufacturing transformation, global competitiveness, and sustainable development.

1.5 Thesis structure

This thesis is divided into seven chapters, which study the servitization transformation of manufacturing enterprises in Shandong Province from theoretical, empirical, and policy perspectives.

Chapter 1: Introduction. This chapter mainly introduces the research background and significance, research topics, research questions and research purposes, as well as research content and methods. The purpose is to clarify the research questions and determine specific research tasks. On this basis, the issues of concern in this study are first proposed, and the significance, core concepts, research ideas, structural arrangements and research methods of the research are elaborated, so as to provide a macro framework for the entire study and help readers have a comprehensive understanding of this study.

Chapter 2: Theoretical Basis and Literature Review. Starting from relevant theories and literature reviews, this chapter defines the concept of manufacturing servitization and sorts out the influencing factors of the digital transformation of manufacturing under the background of digital economy. Based on the existing research situation, it summarizes and refines, and combines TOE theory to construct a theoretical model of the three-dimensional synergy mechanism of technology-organization-environment, specifically discussing the driving role of technology, organization and environment in the transformation of manufacturing servitization, and laying a theoretical foundation for the subsequent discussion of the technology, organization and environment synergy path of manufacturing servitization.

Chapter 3: Research Method. This chapter includes the introduction of research methods, the determination of research objects, and the selection and evaluation of data sources and variables. Through a detailed introduction to the research methods, the foundation is laid for the empirical analysis in the following text; the research samples and their data sources are explained in detail to ensure the representativeness and reliability of the data used; the operation of the research variables is elaborated in detail, including the dependent variable (the level of manufacturing service transformation), independent variables (conditional variables in the dimensions of technology, organization and environment) and control variables (such as enterprise scale, years of listing and enterprise performance), and a regression measurement model is set up to ensure that the model can accurately reflect the research problem.

Chapter 4: Research on the influencing factors and configuration paths of the transformation of manufacturing service transformation. First, this chapter aims to identify the key factors of manufacturing service transformation based on the net effect analysis of enterprise data. To more effectively identify and verify the influencing factors of manufacturing service transformation and provide empirical support for subsequent qualitative comparative analysis, this chapter strictly follows the methodological requirements of quantitative research. Through the enterprise data set in 2023, the study uses a regression model to test the net effect of the main influencing factors of manufacturing service transformation and discusses the analysis results to explore the specific impact of different factors on manufacturing service transformation. Second, configuration research based on the combination of NCA (Necessary Condition Analysis), and fsQCA (Fuzzy-set Qualitative Comparative Analysis) This part is a study on the configuration path of promoting the servitization of manufacturing industry by the three-dimensional elements of technology, organization and environment. Based on the fsQCA method, this chapter explores the multiple paths of promoting the servitization of manufacturing industry by the three-dimensional synergy mechanism of technology, organization and environment, and uses the NCA method as a supplement to fsQCA. Based on the necessity analysis of NCA and QCA (Qualitative Comparative Analysis), the conditional variable configuration analysis is carried out, revealing the key path to achieve servitization under different combinations of conditions, and conducting in-depth analysis and case analysis of different configuration characteristics through typological division.

Chapter 5 is the research conclusion. Based on the above research, this chapter extracts the main conclusions of the research on the servitization of manufacturing enterprises in Shandong Province, clarifies the influence and synergy of technology, organization and environment on promoting servitization, and explores the key path to achieve servitization of manufacturing industry, providing a theoretical basis for policy formulation and enterprise practice.

Chapter 6 is countermeasures and suggestions. Based on the research conclusions, at the practical level, this chapter puts forward targeted countermeasures and suggestions from the two levels of government and enterprise; at the theoretical level, it puts forward contributions to academic theory. At the same time, this chapter summarizes the limitations of the research and looks forward to future research directions.

Chapter 2: Literature Review and Research Hypotheses

2.1 Transformation of manufacturing servitization

Existing research on manufacturing servitization primarily focuses on the concept, economic outcomes, and influencing factors of the transformation. Therefore, this section organizes literature from these three aspects.

2.1.1 The concept of manufacturing servitization transformation

Enterprise servitization transformation refers to a deep change and upgrading of internal value creation models and business processes under the conditions of market competition and technological advancement, transforming the enterprise's value center from a traditional product-oriented approach to a service-oriented one, and making service the core of competitiveness and value creation (H. Chen et al., 2024).

The concept of manufacturing servitization was first introduced by Vandermerwe and Rada in 1988 (Vandermerwe & Rada, 1988), who defined it as "the extension of manufacturing activities into customer-centered service 'bundles'." It is the behavior by which managers actively integrate manufacturing and services to gain competitive advantage (Benitez et al., 2020). The core lies in shifting from a product-dominant logic to a service-dominant logic, and integrating technological advantages from both upstream and downstream of the value chain to escape low-end value chain lock-in (Vargo & Lusch, 2004).

Mont (2001) emphasized that the essence of manufacturing servitization is to treat the function or service of a product as the core offering, rather than simply selling the product itself. Szalavetz (2003b) analyzed the concept from the perspective of the proportion of service elements in manufacturing inputs and outputs, arguing that manufacturing servitization is a new industrial form in which service elements are increasingly integrated into the full process of production and operation, enhancing the fusion between manufacturing and services.

From a dynamic perspective, manufacturing servitization is seen as a process driven by changing consumer demand (G. Lu et al., 2005) and enterprises' need to improve competitiveness (Porter & Ketels, 2003), in which firms shift from traditional goods producers to service providers (Reiskin et al., 1999). The goal is to reposition the firm's value chain from manufacturing-centric to service-centric to enhance value and competitive advantage (Malerba, 2002; Y. Yang et al., 2013).

H. Liu (2019) also viewed servitization as focusing on services but emphasized the integration of products, services, and information to create value. Feng et al. (2020) described it as the process of gaining competitive advantage by providing value-added services. Lee et al. (2016) defined servitized goods as the integration of products with inseparable services, including product-based services like maintenance and after-sales support. Örsdemir et al. (2019) believed that servitization refers to manufacturers earning revenue from services rather than products.

Ma and Li (2019) pointed out that servitization not only involves manufacturers extending into services but also service firms penetrating manufacturing. L. Lu et al. (2024) further emphasized that servitization involves transitioning from product-only offerings to integrated product-service solutions aimed at enhancing customer value and competitiveness. Y. Huang et al. (2023) stressed that servitization is a systemic transformation requiring comprehensive adjustments in organizational structure, business models, and value creation methods.

From the strategic perspective, H. Zhang et al. (2018) defined servitization as a strategic transformation embedding services into the full lifecycle of products. From the perspective of service types, servitization includes product-supporting services (e.g., manufacturing, sales, use) and customer-supporting services (e.g., enhancing user experience and satisfaction) (Mathieu, 2001).

From the input-output perspective, internal services include R&D, operations, value chain management, HR, accounting, legal, and financial services — all of which improve productivity and competitiveness. External output services include maintenance, logistics, installation, support, integration, and financing (Szalavetz, 2003a). Thus, servitization includes input servitization (services as inputs) and output servitization (product-related services) (Sousa & Da Silveira, 2019).

J. Zhou (2024) differing from the traditional input-output approach, proposed a “product-enterprise-industry” three-dimensional model. From the product level, servitization means shifting to providing comprehensive service products (e.g., support, maintenance, consulting). At the enterprise level, it entails restructuring and expanding value chains via integration and modularization. At the industry level, servitization drives deep integration of manufacturing and services, promoting industrial upgrading and competitive positioning.

From the value chain perspective, Y. Liu et al. (2023) argued that servitization helps extend the value chain and improve efficiency. Zhan and Liu (2024) viewed it as a process where firms enhance their value chain position by expanding service business. In the digital economy era, fast technological development reshapes the environment and operating modes of manufacturing, leading to the phenomenon of “digital servitization” (Paschou et al., 2020). T. Zhang et al. (2022) focused on digital transformation and confirmed that digital technology boosts production efficiency, offering new foundations for understanding servitization.

In summary, although scholars define manufacturing servitization differently, a common theme is that its purpose is to meet latent customer needs by shifting from offering products to “product + service” bundles (Zhan & Liu, 2024). It is a multidimensional and systemic strategic change that transforms how enterprises create value, positioning services as the core source of added value.

Servitization manufacturing turned out to be the subject of conceptual development in terms of evolution, as the technological environment and market forces, as well as theoretical comprehension, provided clear changes to its vision. This chronological review of the histories of servitization studies follows the journey of the study through its initial definition, to its current online embodiment and emphasis on influential scholarly works, as well as theoretical and conceptual transitions. Initial Conceptualizations as Service Packaging The intellectual literature on servitization has a late 20th century origin, with academics seeing servitization mainly in terms of service addition to tangible goods. One of the first formal investments, which defined servitization, was given by Vandermerwe and Rada (1988) who defined the concept as a process that involves extending the manufacturing processes to customer-led service packages. This view made services an add-on to products so as to add customer value by providing services that add to the value of products sold, examples of which include: maintenance, installation, or training of the product. In the early 2000s, academicians such as Mont (2001) elaborated this notion by prioritizing functional utility rather than ownership of the products. The concept of servitization was first defined as a model by Mont (2001), in which the companies provide the functions of the product or the services of the product instead of a product itself, setting the stage what was later to be referred to as Product-Service Systems (PSS). At the same time, Mathieu (2001) differentiated product-supporting and customer-supporting service and acknowledged the fact that servitization involved not only post-sales services but also fully integrated solutions aimed at improving the experience of users. The initial research regarded servitization as a competitive positioning tool to distinguish products in the competitive environment, concentrating on the bundling of services, as opposed to the core change in business models. It was always about the products being the primary attribute, and services being the add-ons (Mont, 2001; Vandermerwe & Rada, 1988) . Switch to Strategic

Transformation Entrenchment The latter trend of the First Decade of the 2000s was a paradigm shift in the understanding of servitization among scholars who started thinking of it as a strategic re-alignment of firm value chains. Another dramatic shift, according to Porter and Heppelmann (2015), is viewing what they term smart, connected products as a critical juncture by presenting the case of servitization focusing on how manufacturers are capable of breaking product-constrained business models and venture into service-focused businesses.

The process of conceptualization of servitization of manufacturing has taken different theoretical prisms and each of them has provided different insights into the encounterment of its mechanics and mission. The perspectives are divided into three broad paradigms in this sub-section, which presents a more organised understanding of the various scholarly approaches in studies on the idea of servitization.

This school of thought did not consider servitization as an appendage, but as an avenue of designing new ways of value-creating activities, right up to the engagement with the customers. At the same time, the theoretical basis of this strategic shift was stated by Service-Dominant Logic (SDL) developed by Lusch and Vargo (2014). According to this speculation, the unit of actual economic exchange was a service (not goods). SDL also focused on co-creation of value between customers and firms that helped to counter the notion of goods-dominant logic that had dominated in production processes (Vargo & Lusch, 2004). Other studies such as Baines and Lightfoot (2013) also added that servitization involved system change within the organisation including change in management structure and resources and capabilities. Servitization came to be considered by the end of the 2010s as an overarching, strategic change and not as a tactical one. Research was devoted to its effects on the competitiveness of firms, changes in their value chains and required organizational adaptations to facilitate the service-oriented business models (Lusch & Vargo, 2014; Porter & Heppelmann, 2015).

Digital servitization as a systemic integration in the 2020s: the research on servitization has passed the point of intersection with digital transformation and nurtured the theory of digital servitization. The development of IoT, AI, and big data analytics triggers this step to define servitization as an integrative process of adopting digital technologies to service deliverables to establish smart product-service systems. L. Lu et al. (2024) define digital servitization as a shift of the offering of products to all-inclusive product-service solutions through real-time data flows, and Y. Huang et al. (2023) indicate the importance of digital servitization in the re-engineering of organizational structures, business models, and value creation processes. Authors such as T. Zhang et al. (2022) and Paschou et al. (2020), among others, point at the use of digital technologies to deliver predictive services, customized solutions, and ecosystem collaboration.

To elaborate, IoT sensors installed on the products create a stream of usage data used by firms to offer proactive maintenance services, whereas AI algorithms process the behavioral patterns of customers to co-create personalized service experiences. It is the transition of the traditional servitization, as the period focuses on information-driven decision making and automated service delivery, turning manufacturers into digital service orchestrators (Y. Huang et al., 2023; L. Lu et al., 2024). The history of the development of the concepts of servitization itself (service bundling, strategic transformation, digital integration) is the interaction of theoretical novation and technological advancement. This chronology illustrates the fact that servitization is not a stagnant feature but dynamic process which is influenced by the transforming market demands and technological proficiency and which put the modern assessment of its financial outcomes and determinants in perspective.

2.1.1.1 Theory on product-service systems (PSS)

The product-Service System (PSS) paradigm, whose inspiration was born by Mont (2001) and continued by Mathieu (2001), redefines the manufacturing industry as a source of functional value, but not of tangible products. The very essence of the PSS theory is the fact that due to such a shift in focus, firms will be able to be more sustainable and competitive as they no longer transact via ownership of products but rather provide other values through services. According to Mont (2001), the meaningful difference witnessed in terms of customer relationships under PSS is the transformation of the transactional relationship between the products and the agreements between the parties that are now more characterised as being function-oriented i.e. leasing, maintenance, or the performance-based service models.

Mathieu (2001) presents a typology of PSS, splitting it down into the following categories:

Outcome based services: such that businesses are paid on performance results achieved (i.e., an equipment manufacturer is paid on machine uptime as opposed to the actual sale of the machine);

User-oriented services: that are aimed at enabling the usage of the product (e.g. leasing models allowing customers to use products but leaving ownership to the owner).

This paradigm negates conventional manufacturing logic in terms of integration of different services within product lifecycle. As an example, PSS-oriented company may decide to design their products in a manner that assists in long-term service delivery, i.e. by making them modularly repairable and upgradeable, instead of manner that would maximize single sale profitability (Mont, 2001). PSS view has specifically contributed a lot in the area of sustainability research as it fits well in the concept of the circular economy that focuses on minimizing wastes of materials as well as prolonging product life.

2.1.1.2 SDL service-dominant logic

Service-Dominant Logic (SDL) as developed by Vargo and Lusch (2004) symbolizes a theoretical transition of a good-centric to service-centric value creation. SDL contends that all forms of economic transaction are service oriented and goods are means of services delivery. The purpose of manufacturing companies is redefined in this paradigm to refer to the companies as the orchestrators of value co-creation, instead of being sellers of the final product.

Some of the major principles of SDL are:

Service as the ultimate element of exchange: Contrary to goods-dominant logic where products are treated as specific items, SDL postulates that clients are interested in the services that can be made possible by products (Vargo & Lusch, 2004). A case in point is: a client buying a printer is in fact buying the service of copying documents.

Value co-creation: The value is not initially built-in products but instead created in the interaction between the firms and the customers making it. This is in contrast with the classical arrangement that value exists on the products before they are sold (Lusch & Vargo, 2014).

Service combination abilities: Companies have to establish organizational skills to create, provide and maintain service programmes to go with the products (Vargo & Lusch, 2008).

SDL has played a central role in redefining servitization as a strategic action other than an add-on action of services. It highlights the necessity of manufacturers to re-align their value chain to the needs of consumers by integrating services in order to build long-term relationship value/value-in-use as opposed to transactional value (the value of short-term exchange of products, (Porter & Heppelmann, 2015).

2.1.1.3 Digital servitization theory

The theory of digital servitization is the result of the interplay between digital technology and conventional research on servitization (Paschou et al., 2020; T. Zhang et al., 2022). It establishes a different paradigm according to which integrated product-service systems are achieved through smart products and data analytics. The perspective differs in that it is opposite to the traditional views of PSS and SDL by putting emphasis on changing transformation in reconfiguring service delivery with the help of digital infrastructure.

The characteristics of digital servitization are:

Product-service integration with IoT: Active products can be transformed into smart products: with connectivity and sensors, these products can produce real-time usage data that the firm will be capable of utilizing in providing predictive services (e.g., offering maintenance services as needed in line with the actual state of the equipment instead of offering them after a preset period of time) (Paschou et al., 2020).

Data-based innovative services: Services insights that are built on data generated by the product, e.g., determine service opportunities (offering individual service packages, anticipating project issues, among others) (T. Zhang et al., 2022).

Value creation in ecosystems: Digital technologies promote the work among supply chains so the manufacturers can collaborate with partners and customers and provide services cooperatively (Porter & Heppelmann, 2015).

Using the example of a vendor of industrial equipment that may exploit digital servitization, the IoT data may be applicable to optimize the maintenance intervals, and this is because the AI algorithms will forecast component failure, and thus, the conventional after-sale service reinvents it, making it become proactive and data-driven. Unlike the classic servitization, this paradigm is associated with the usage of real-time data flows, automalized decision-making that would allow delivering more dynamic and context-sensitive services (Y. Huang et al., 2023).

Placing servitization in the context of these theoretical frameworks, the review points to the transition of the logic of product- to service-based, which culminated in the data-driven service ecosystems of today. Both paradigms reveal different aspects of the motivations of servitization, mechanisms and outcomes and give a firm basis in the following discussion of economic impact and drivers.

2.1.2 Economic consequences of manufacturing servitization transformation

There is disagreement in academia regarding the impact of servitization on firm performance. One view argues that greater servitization enhances firm performance, such as increased income and profits (C. Zhao, 2021). The integration of service and production elements can restructure business models and external environments (Frank et al., 2019), stimulating innovation and reducing redundancies. It can also lower management and operating costs (L. Shen et al., 2021) and enhance innovation capacity.

However, another view emphasizes the “servitization paradox,” where servitization may not always lead to better performance. Neely (2008) found that servitized firms often underperform in terms of net profit compared to product-focused firms. Over-expansion into services can increase complexity and costs without guaranteed returns.

Recent studies highlight the synergy between digitalization and servitization. Research shows that digitalization plays a mediating role between servitization and innovation (L. Shen et al., 2021), and their interaction can positively influence financial performance.

Servitization also enhances firms' positions in the value chain. As globalization progresses, the relationship between servitization and global value chain (GVC) participation has become a key research topic. B. Liu et al. (2016) empirically showed that embedding services improves firm integration and influence in international supply chains. Hao and Huang (2019) confirmed that input servitization improves Chinese firms' GVC positions, though the effect is non-linear and forms an inverted U-shape (Y. Du & Peng, 2018).

Other studies explored mechanisms linking servitization and GVC participation. Results show that integrating service resources improves resource allocation efficiency (S. Zhu et al., 2021), lowers production and transaction costs, and boosts productivity (Frank et al., 2019), thus deepening GVC integration (Francois et al., 2015). Technological innovation, economies of scale, and differentiated competition are also critical to GVC upgrading (Y. Du, 2019).

From a product perspective, servitization enhances product quality, export sophistication, and intermediate input methods, improving competitiveness in GVCs (Arnold et al., 2016; Heuser & Mattoo, 2017; Lodefalk, 2014).

Studies concerning the so-called servitization paradox (Neely, 2008) have shown that the signs of the paradox as well as its extent are preconditioned by various contingency factors. Such moderators offer useful insight into the fact that the economic consequences of servitization are characterized by heterogeneous results in firms, industries, and regions that are essential to understanding the effects of servitization.

The article by Santamaría et al. (2012) shows that the performance of servitization is non-linearly affected by a firm size. The paradox may be aggravated by resource limitations on small and medium enterprises (SMEs) including the following problems: limited R&D funds or specialized talent. To illustrate, when the fixed costs of service infrastructure are high, SMEs might not be able to absorb them that is why they become less profitable though servitized (Santamaría et al., 2012). Conversely, the extensive organizations have the chance to combine services thanks to the economies of scale, decreasing the possibility of poor performance (Frank et al., 2019).

As L. Shen et al. (2021) determine, digital maturity is one of the moderators. Companies with already-developed digital capabilities (i.e. data analytics systems or IoT integration) are in a better condition to overcome the paradox. Digital tools allow in real time tracking the implementation of the rendered services, cost optimization, and anticipation of the needs of customers, reducing the operational complexity problem, which is frequently the consequence of servitization (L. Shen et al., 2021; T. Zhang et al., 2022).

According to the findings of Neely (2008), the paradoxes of servitization are greater in high-volatility industries (e.g. technology or fashion) where the changes in the operation of the market may lead to the service investments becoming invalid. Services offer more predictable income and so the paradox is less likely to occur in stable industries (e.g. utilities). In parallel, Q. Huang and Huo (2014) demonstrate the fact that intensive competition pushes the firms to servitize as the method of differentiation, yet it may go awry in cases when the service provisions do not win the market share.

Juris Pillarisetty lays out the complexity in the value chain and embeddedness of service, the primary focus and highlights of the study.

Frank et al. (2019) associate the complexity of value chain with outcomes of servitization. As there are complex supply chains involved in such highly organized industries (such as aerospace or automotive) services such as predictive maintenance or components life cycle management become more returning since they are strategic. On the other hand, basic value chains can also lack sufficient warrant on inputs into these services, thus, enhancing the possibility of the paradox (Frank et al., 2019; B. Liu et al., 2016).

B. Zhang and Jin (2020) reveal such an inverted U-shaped correlation between the dimension of institutional quality and the performance of servitization. The optimal results of servitization are created with the moderate level of institution support (e.g., balance of regulation and tax incentives), whereas too much (or too little) support worsening efficiency. To give an example, regions associated with excessive regulation might have increased compliance expenses that undermine the increase in service revenues (B. Zhang & Jin, 2020; J. Zhou, 2024).

According to Guo et al. (2024), there is a regional enabler, called digital infrastructure. Regions, which are characterized by a strong owing network, cloud services as well as industry internet platforms, will be in an exemplary position to integrate their services with the end results being a decrease in the incidence of the paradox. On the contrary, service areas that have low-quality digital infrastructure make adoption very expensive, which restricts the benefits of servitization (Guo et al., 2024; N. Zhou & Bao, 2022).

The contingency factors in question speak to the fact that the economic implications of servitization are local and not uniform. Incorporation of firm, industry, and regional features enables the researchers and practitioners to forecast and address the servitization paradox more precisely since they convey the strategies in the light of realities. Such subtle knowledge is extremely important in the further analysis of the factors of influence and the formulation of a hypothesis.

In conclusion, most scholars view the economic impact of servitization positively, believing it enhances GVC positions, firm performance, and total factor productivity—prompting further exploration of its drivers.

2.1.3 Review of key influencing factors in manufacturing servitization transformation under the digital economy

With a deepening understanding of the connotation of service-oriented manufacturing, research on its driving factors has gradually gained attention. Scholars have explored various factors influencing the transformation of manufacturing toward servitization. Y. Li et al. (2022) argued that the transformation is the result of multiple interacting factors. Q. Huang and Huo (2014), based on international input-output data, concluded that independent innovation capability, a fair competitive environment, service innovation capacity, and the level of human capital are key drivers. Qi et al. (2014) believed that the intensity of industrial competition, technological level, degree of servitization, and resource constraints significantly affect the transformation. Lay et al. (2010) and Falk & Peng (2013), focusing on European manufacturing, discussed strategic motives behind servitization and identified factors such as service strategy, product category, supply chain position, and the proportion of service-related employment.

Q. Huang and Huo (2014), using data from multiple countries, empirically found that service sector productivity, transaction costs, human capital, innovation capacity, and manufacturing competitiveness all positively influence manufacturing servitization. J. Liu and Zhao (2008) pointed out that external factors like resource constraints, market volatility, and technological changes, along with internal factors such as executive attention, employee culture, and internal division of labor, play key roles in the adoption of servitization strategies. X. Li & Liu (2019) research found that product complexity together with consumption upgrading and next-gen information technology development and growth sustainability provide the main drivers.

The study conducted by Mastrogiacomo et al. (2019), demonstrated that companies across different countries are now focusing on developing better customer relationships as well as supply chain management and post-sales customer support. They noted that servitization types and degrees vary by firm size, location, and industry. Various research investigated how international trade impacts as well as how market openness (Breinlich et al., 2018), and foreign investment liberalization (Song, 2021) affect companies.

It is evident that research on drivers and influencing factors of manufacturing servitization spans diverse perspectives. A deeper analysis reveals that most studies center on the effects of technology, organization, and environment—forming a solid foundation for this study's exploration of servitization pathways. Therefore, the following review is structured around these three dimensions.

(1) Technological Factors

With the rapid advancement of information technology, its role in driving enterprise servitization has drawn increasing attention. Many scholars have investigated how technological progress shapes servitization. Vendrell-Herrero et al. (2017) pointed out the close relationship between servitization and digital technology, emphasizing that technological development positively affects manufacturing servitization.

Huxtable & Schaefer (2016), using UK firm data, proposed a framework based on IoT, big data, cloud computing, and AI, illustrating their role in promoting servitization. Santamaría et al. (2012) found through Spanish data that technologically advanced firms are more inclined toward service-oriented models, suggesting that cutting-edge manufacturing technologies facilitate servitization. Kohtamäki et al. (2013) stated that digital transformation reduces search and transaction costs, thus enhancing servitization levels.

C. Zhao (2021) confirmed through Chinese listed firm data that digital transformation significantly promotes servitization via two key channels: (1) digital technology boosts innovation capacity, enabling high-value-added services; (2) it optimizes human capital structure, improving efficiency and thus driving servitization. R. Gao (2024) also found that digital development positively impacts servitization transformation. Struyf et al. (2021) highlighted how digital technologies help firms accumulate expertise, integrate dispersed resources, and drive collaboration across the value chain—key mechanisms for upgrading service models. Raymond et al. (2009) showed that advanced manufacturing tech significantly supports SME product innovation.

Since 2020, over 3 million industrial robots have been deployed globally. AI technologies represented by these robots are expected to profoundly impact manufacturing servitization and bring revolutionary changes to business decision-making (Acemoglu & Restrepo, 2022). Luo et al. (2023), using text mining on A-share listed Chinese manufacturers, analyzed the effect of big data. Their findings revealed a U-shaped relationship—low levels of big data application may hinder servitization, but once a threshold is crossed, its impact becomes strongly positive.

Furthermore, the effect of big data varies by service sector openness and competition. For firms in less open but highly competitive markets, the U-shaped relationship is especially evident.

In summary, technology is the core driver of servitization (Santamaría et al., 2012), reshaping production and providing strong support. As digital tech continues to evolve, future servitization trends will likely become more pronounced, creating new business models and competitive advantages.

(2) Organizational Factors

Internal organizational elements play a crucial role in successful servitization. Scholars have examined various internal drivers. Falk & Peng (2013) viewed human capital as a key service element, suggesting its input facilitates servitization. Y. Li et al. (2022) emphasized that high-quality service teams provide strong support for transformation. As Baines & Lightfoot (2013) noted, employee skill requirements evolve with servitization. Enterprises must enhance training in digital and service skills to build adaptability W. Xie et al. (2020).

Xiao et al. (2014) verified the positive impact of human capital wages, IT investment, and strong customer relationships on service innovation. Y. Chen et al. (2023) found that top management team characteristics influence servitization differently.

Besides human capital, scholars also studied management models. Vendrell-Herrero et al. (2017) argued that structural and managerial transformations are necessary for adapting to digital challenges. Kohtamäki et al. (2019) suggested that firms should shift from production-centric to customer-centric management. Zhan et al. (2022) also emphasized that organizational restructuring is key. Lee and Edmondson (2017) added that flatter structures help firms respond faster to market changes.

Scholars also explored the role of organizational culture. Raddats et al. (2019) believed customer-centric cultures support smooth transformation. Z. Yang (2018) also noted this foundational cultural role.

In short, under the digital economy, factors such as structure, management, human resources, and culture interact to drive servitization. Organizational optimization helps firms meet new challenges and achieve high-quality transformation.

(3) Environmental Factors

External environment is also critical. Tong and Zhang (2021) noted that producer services liberalization significantly boosts servitization. N. Zhou and Bao (2022) found that digital services openness promotes transformation via resource allocation, innovation, and labor substitution effects—with spatial spillovers as well.

Qi et al. (2021) investigated factors influencing both input and output servitization, finding that industry competition, policy environment, and service import openness significantly affect levels of transformation.

Environmental dynamism generally increases firms' propensity to transform, whereas complexity can undercut the benefits of change; empirical work links dynamism to stronger innovation and strategic adjustment, while showing that complex conditions may blunt adoption outcomes (Chaudhuri et al., 2023; X. Wang et al., 2021). Conversely, other evidence indicates that uncertainty/complexity can spur firms to orchestrate and diversify resources—supporting transformation (H. Chen & Tian, 2022).

Firms in more open environments also transform more readily: recent studies on services-trade openness in China find that opening improves upgrading paths and resource access conducive to transformation (Shu et al., 2025). From a spatial lens, industrial co-agglomeration fosters upgrading via innovation and knowledge spillovers, though the effect is nonlinear (inverted-U) once congestion costs emerge (N. Yang et al., 2022).

Institutional conditions matter too: institutional support positively affects manufacturers' servitization performance, with internal organizational resources—business-model and technological innovation—mediating this relationship (Cao et al., 2022). Related work on regulatory/institutional pressure often shows inverted-U patterns—"too little" or "too much" pressure is sub-optimal for sustained transformation (Gong et al., 2020).

Finally, across external challenges, digital (platform) transformation capability stands out as a foundational, built-in capability for mobilizing and reconfiguring resources to enable transformation (Z. Liao et al., 2024).

Environmental factors influence organizations on both broad (city openness and agglomeration) and middle-scale (institutional) levels.

The evaluation of published studies establishes that manufacturing servitization depends substantially on technological, organizational and environmental elements. The servitization process emerges from multiple interacting factors which result in such a comprehensive transformation. This research studies manufacturing servitization through the examination of the TOE framework.

2.2 TOE framework and the servitization transformation of manufacturing

2.2.1 TOE theoretical framework

The TOE (Technology-Organization-Environment) model is a theoretical framework used to explain the challenges and influences that organizations face when adopting new technologies. It was first proposed by Tornatzky et al. (1990) emphasizing the influence of multi-level technological application contexts on technological development. It is suitable for analyzing technological contexts and is mainly used to explain organizations' technological integration and adoption behaviors (Y. Yu & Chen, 2024). As a general innovation adoption model, it has been widely applied in various fields of enterprise management and development.

TOE theory holds that when an enterprise undergoes technological or strategic transformation, its decision-making and implementation processes do not depend solely on the enterprise’s own technological resources and capabilities but are also affected by internal organizational conditions and the external environment. The framework integrates theories such as the Technology Acceptance Model (TAM) and Innovation Diffusion Theory (IDT), developing a comprehensive analytical framework based on technology application contexts (Qiu, 2017), with a main focus on how the technological context affects the outcomes of technology applications.

Compared to TAM and IDT, the TOE model incorporates both, thus offering unique advantages in comprehensiveness and multi-dimensional analysis, evolving into a context-based integrated analytical tool. TAM emphasizes individual-level user acceptance of new technologies, mainly through the dimensions of perceived ease of use and perceived usefulness to explain attitudes and behaviors. Innovation Diffusion Theory focuses on how technological innovations spread within a social system, highlighting factors such as relative advantages, compatibility, and complexity. Unlike these, the TOE model focuses more on organizational-level technology adoption, combining technological, organizational, and environmental factors, and stressing the internal and external conditions that enterprises face during adoption. As such, TOE offers a broader and more holistic perspective than TAM and IDT for explaining organizational technology integration and adoption behavior.

The TOE framework classifies the factors influencing technology innovation adoption and its effectiveness into three categories: technology, organization, and environment. Technological factors include characteristics related to innovation itself, covering both the nature of the technology and the technical conditions within the organization. Organizational factors relate to the organization's size, structure, systems, and resources. Environmental factors represent the broader social context in which the organization operates. As a general classification framework, the TOE model systematically examines multi-level, multi-dimensional factors both inside and outside the organization and features clear criteria for categorizing influencing elements (Tan, 2016).

Therefore, since its inception, the TOE framework has been widely applied in research areas such as e-commerce, electronic data interchange, and enterprise management systems. In the field of manufacturing transformation, J. Li et al. (2023) analyzed the digital-driven transformation path of Shandong's textile and garment industry from the three TOE dimensions. J. Zhou (2024) used the TOE framework to explore how the digital economy empowers Shandong's manufacturing transformation, identifying technological innovation, organizational change, and policy environment as key factors. D. Wang and Wu (2020) focused on the mechanism through which the digital economy promotes manufacturing upgrading, emphasizing the coordinated effects of technical support, organizational restructuring, and the external environment. X. Liao and Yang (2021) based on the TOE framework, empirically evaluated the impact of the digital economy on manufacturing transformation in the Yangtze River Delta, revealing the importance of technology application, organizational learning, and environmental adaptability. C. Li et al. (2020) from an industrial chain perspective, explored the mechanisms by which the digital economy drives manufacturing transformation and upgrading, highlighting the core roles of technology integration, organizational coordination, and ecosystem construction.

Through extensive empirical research, the effectiveness of the TOE framework in explaining issues related to manufacturing transformation has been well validated. Therefore, this study introduces the TOE framework into the research of manufacturing servitization transformation, analyzing the impact of the three dimensions—technology, organization, and environment—on this process. See Figure 2.1 for details.

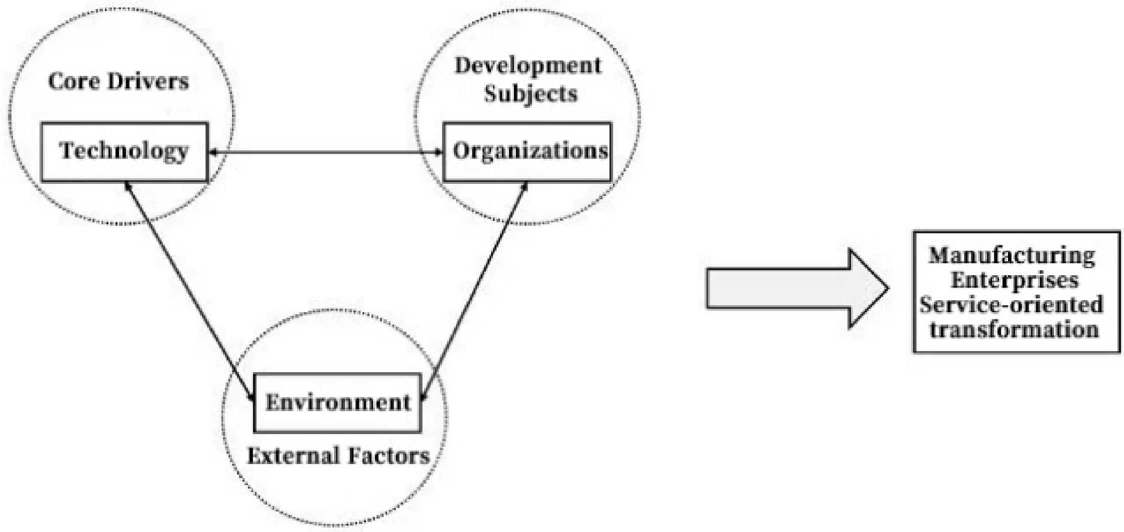

Figure 2.1 Servitization transformation of manufacturing under the TOE framework

The TOE (Technology-Organization-Environment) framework that appears to be widely used to measure technology adoption in an organization is based on theoretically distinct traditions, which are underlying each of the dimensions. Under this sub-section lies the intellectual underpinnings of the TOE model where clarification of the target theoretical principles of the analysing framework is made.

2.2.1.1 Informational backgrounds of technology dimension

The area of technology in the TOE framework is heavily grounded in the theory of innovation adoption (Tornatzky et al., 1990), which established main characteristics of technological innovations that determine the process of adoption by the organizations. Their tome study on the technological innovation processes points to two important constructs: relative advantage and compatibility.

Relative advantage: How well a certain technology is felt to be superior to the current solutions (Tornatzky et al., 1990). The meaning of this to the concept of servitization means the extent in which digital technologies (e.g. IoT, AI) are considered to improve service delivery efficiency or customer value over traditional means. As an example, T. Zhang et al. (2022) show that IoT-enabled predictive maintenance results in relative advantage, i.e., it decreases a significant cause behind servitization decision of manufacturers, e.g., unplanned downtimes.

Compatibility: how well a technology fits with current values, practices and needs of an organization (Tornatzky et al., 1990). The requirement of compatibility is very significant to servitization because digital technologies need to be connected with the manufacturing process and service goals of a firm. N. Zhou and Bao (2022) demonstrate it regarding the ease of integrating the traditional production lines with service modules through compatible digital infrastructure.

The example of the framework of Tornatzky et al. (1990) also involves variables such as a complexity, trialability, and observability that have been adapted to servitization research on the assumptions of why specific technologies (such as cloud-based service platforms) are embrace faster than others. Such a theoretical background emphasizes that technological adoption in servitization is not only related to technological progress but also to the perceived technological-organizational-fit.

2.2.1.2 Theoretical origins of the dimension of the organization

Organizational aspect of TOE is based on the traditional organizational theory, especially the mechanistic organic paradigm offered by Burns and Stalker (1961). In their study of industrial companies in dynamic contexts, they did distinguish between:

Mechanistic Structures: Vertical, bureaucratic and rule driven and it is appropriate in stable environments where nothing much happens.

Organic Structures: Nonhierarchic, loose and amalgamative, structures that operate within an uncertain environment that necessitates adaptive problem solving (Burns & Stalker, 1961).

Within the environment of servitization, this theory determines the fact that organizations should shift the mechanistic framework to organic, to promote the service-oriented models. As an example, it is revealed by Eggert et al. (2014) that decentralized decision-making (a soft quality) helps manufacturers more effectively address customer services needs, and that cross-functional collaboration, which requires organic structures is the keys to the interdependent relationship of the products and services.

Also, the organizational aspect of TOE parallels resource-based theory (Barney, 1991) and dynamic capabilities theory (Teece, 2007), which focus on implementation of technology as mediated by organizational resources and not capabilities. Zhan et al. (2022) use this lens to demonstrate that the more successful companies engage in servitization in cases of firms with dynamic capabilities, including the capacity to reconfigure resources to deliver services. The logic of the Burns and Stalker (1961) framework offers a rationale to why the design of an organization has to change to accommodate the technological frontier in the area of servitization.

2.2.1.3 Theoretical origins of the dimension of the environment

The environmental aspect of TOE relies on the institutional theory, especially DiMaggio and Powell (1983), who isolated three categories of the institutional pressures which influence the organizational behavior:

Coercive Pressures: They are legal or regulatory demands, which make an organization conform to some practices (DiMaggio & Powell, 1983). This can be in the form of government regulations, as in the case of servitization, related to encouraging service-based manufacturing processes (subsidy of digital service campaigns (J. Zhou, 2024), or an industrial standard establishing service integration (Foster & Azmeh, 2020).

Normative Pressures: The social expectation and professional standards of the norms that drive organizational decision making. To illustrate, norms can be created on service quality by industry associations, which forces manufacturers to use servitization to legitimize their industry (Paschou et al., 2020).

Mimetic Forces: Uncertainty caused behavioral imitation in which an organization uses action that is viewed as being effective by other companies (DiMaggio & Powell, 1983). Where there is a highly competitive environment, manufacturers can mimic market leaders on their use of servitization strategy to keep pace with them as witnessed in the study of participation in global value chains by B. Liu et al. (2016).

This dimension is further complemented with resource dependence theory which alerts on the fact that organizations rely on external environments to avail the necessary resources to the organization (e.g. funding, talent, market access) and this affects the way the organizations react to the environmental demands (Pfeffer & Salancik, 1978). Y. Du and Peng (2018) use it to demonstrate how the environmental uncertainty pushes firms to pursue service-based sources of revenue as a diversifying of resources strategy.

The TOE framework helps to identify the role of external forces (including regulatory requirements and competitive mimicry) in dictating the servitization path of the firm on the site of the environmental dimension because of grounding the environmental dimension into institutional and resource dependence theories.

The theoretical unfolding of the dimensions of TOE explained that the framework is not a model unto itself but a combination of proven theories of innovation adoption, organizational design and institutional analysis.

2.2.2 Technological drivers of servitization from the perspective of resource-based view

The Resource-Based View (RBV) emphasizes that the uniqueness and heterogeneity of a firm's resources are the core sources of sustainable competitive advantage. From this theoretical perspective, a company's competitiveness primarily stems from its possession and control of rare, hard-to-imitate, and non-substitutable resources (Barney, 1991). A firm's technological R&D activities are essentially a process of cultivating and acquiring heterogeneous resources, serving as a source of competitive advantage. Through technological innovation, enterprises can realize service innovation and develop unique core competencies. Manufacturing servitization essentially involves extending a company's core resources and capabilities into the service domain to meet customer demands for integrated solutions. As servitization accelerates, technological resources, as key internal strategic assets, play a critical role in driving this transformation.

The uniqueness and complexity of technological resources provide a solid foundation for implementing servitization strategies. On the one hand, advanced technological resources can enhance production efficiency and operational flexibility, helping companies transform from single-product providers into integrated solution providers. Digital technologies enable firms to more efficiently and systematically collect and share information about competitors, competitive services, and new customer needs (De Jong & Vermeulen, 2003), optimize labor, equipment, and raw material usage, thereby reducing costs and improving product quality and reliability, granting manufacturing firms higher productivity (Naik & Chakravarty, 1992). They also enhance a firm's strategic flexibility, enabling it to respond more effectively to environmental changes and uncertainties (Hofmann & Orr, 2005), and serve as vital tools for developing or improving services and processes (Hipp & Grupp, 2005). On the other hand, the inimitability and path dependence of technology strengthen a firm's market position in the competitive landscape of servitization. The application of technology can foster interactive learning processes, helping firms build learning capabilities and establish unique competitive advantages (Pandza et al., 2005; Sohal et al., 2006). This not only enhances product value but also supports a deeper servitization transformation through smart and digital services.

Digital technology is the foundation for servitization in manufacturing enterprises, offering opportunities to develop customized value propositions based on higher quality services and relationships (Rust & Huang, 2014). Z. Huang et al. (2022) pointed out that digital technology can promote the servitization transformation of manufacturing firms and enhance their value creation capacity. From a resource perspective, Y. Wang et al. (2020) found that the application of digital technologies helps manufacturing firms reconstruct production processes and optimize resource allocation efficiency, thereby moving up the high-end value chain Sklyar et al. (2019) believed that servitization involves the use of digital technologies to reshape service activities and processes. The application of digital technologies not only fosters the development of complex and innovative service products but also further drives the servitization process (Grubic, 2018). IoT technologies can extend the manufacturing value chain, drive industrial restructuring, and facilitate the transformation toward servitization (Rymaszewska et al., 2017). The adoption of technologies such as IoT analytics and artificial intelligence not only enhances service delivery functions but may also alter how those functions are performed (Ardolino et al., 2018). This transformation enables the realization of service-oriented business models (Adrodegari & Saccani, 2017) and contributes to reshaping industry competition (Porter & Heppelmann, 2015). Product-centric enterprises, through the adoption of digital technologies, can enhance service delivery efficiency, increase product and value-added service value, and at the same time transform business processes and models (Lerch & Gotsch, 2015).

2.2.3 Organizational perspective on servitization of manufacturing under the dynamic capabilities theory

The Dynamic Capabilities Theory (DCT) posits that a firm's ability to sense and seize external opportunities and reconfigure internal resources in dynamic environments is the key to sustained competitive advantage (Tong & Zhang, 2021).

Zhan et al. (2022) through empirical research, found that dynamic capabilities play a major role in the realization of manufacturing servitization under the digital economy context, thereby introducing the theory into servitization research. In the process of servitization transformation, a firm's ability to gain competitive advantages is closely tied to its dynamic capabilities. How to enhance organizational capacity, optimize internal resource allocation, and restructure organizational structure to respond to complex market environments and rapid technological changes become the core issue in servitization. Dynamic capabilities in this context refer to a firm’s ability to perceive market demand, integrate technological resources, and restructure organizational architecture, thus supporting the shift from a single product manufacturer to an integrated service provider.

The "manufacturing + service" production model in the servitization process requires companies to systematically manage existing knowledge and reconfigure resources to reduce redundancies in production (Hallstedt et al., 2020). The dynamic capabilities theory further emphasizes that enterprises must intelligently allocate resources to support their strategic goals. Whether tangible resources such as equipment and raw materials, or intangible assets like expertise and skills, all need to be efficiently integrated to align with the needs of a servitization strategy (Coreynen et al., 2020). Reducing organizational management costs and improving management efficiency can effectively promote the deepening of manufacturing servitization (Luo et al., 2023).

The transition from manufacturer to service provider requires a shift in organizational model (Raja et al., 2018). In today's highly competitive industrial market, servitization is a key strategic choice for many leading manufacturers to differentiate themselves by offering value-added services. Successful servitization requires a servitization strategy that includes major shifts in business models, management philosophies, and methods. Ahamed et al. studied Japanese manufacturing firms and found that organizational factors such as leadership, vision, and marketing affect the effectiveness of servitization strategies (Ahamed et al., 2013). The transition to servitization demands organizational change to support service delivery, which includes new organizational principles, structures, processes, and the redeployment of key resources from traditional manufacturing to new structures, capabilities, and human capital (Oliva et al., 2012).

2.2.4 Environmental perspective on manufacturing servitization under the resource dependence theory

The Resource Dependence Theory (RDT) starts from the perspective of an enterprise's dependency on the external environment, emphasizing the necessity for firms to interact and adjust in order to obtain critical resources (Qi & Ge, 2022). It views the enterprise as an open system, where strategic behavior is the result of internal and external environmental interactions (Matarazzo et al., 2021). The survival and development of firms heavily rely on obtaining external resources, which are often controlled by other entities in the environment. From the RDT perspective, manufacturing servitization transformation can be seen as a strategic choice by enterprises to integrate external environmental resources, enhance their ability to cope with uncertainty, optimize resource allocation, and improve market competitiveness.

Congden emphasized the need for “fit” between technology and its implementation environment (Congden, 2005). The success of servitization depends not only on the manufacturer’s ability to use internal capabilities and resources, but also on its ability to navigate the market and industry environment (Parida et al., 2014). The firm’s management approach and development strategy should align with its external environment. A favorable external environment is a prerequisite for implementing a servitization strategy (Z. Wei & Wang, 2021). Turunen et al. explored the impact of organizational environments on servitization, finding that the ability of industrial organizations to shift toward service offerings depends on the environmental context, and that regulatory requirements increase demand for product-related services, encouraging servitization (Turunen & Finne, 2014). Dmitrijeva et al. argued that environments affect managers’ efforts to adapt organizations to specific environmental demands (through strategy formulation and implementation), thus influencing servitization. Smaller organizations, due to limited product portfolios and higher specialization, face greater transformation pressure and are more susceptible to environmental influences (Dmitrijeva et al., 2020).

From the resource acquisition perspective, Y. Du and Peng (2018) found that environmental uncertainty affects the resource acquisition strategies of manufacturing firms, which in turn influence their servitization paths. J. Zhang et al. (2019) focused on institutional environments, demonstrating that favorable institutional environments help firms obtain critical resources and promote servitization. Some scholars also examine the interaction between environmental factors and firm characteristics. For example, C. Li et al. (2020) found that the interaction between environmental uncertainty and technological capabilities influence servitization levels. H. Zhang et al. (2018) further pointed out that the technological environment promotes servitization by enhancing innovation, while the market environment does so by shaping customer demand. Thus, environmental factors impact servitization in complex, interactive ways involving dynamic matching between external environments and internal firm resources and capabilities.

Environmental factors influence servitization by affecting resource access, capability building, and strategic choices, shaping both the external conditions and internal drivers for transformation. However, the mechanisms and paths through which these factors exert influence still require deeper investigation—particularly under the digital economy, where the nature of the relationship between environment and servitization may evolve. Resource Dependence Theory emphasizes the mutual dependence between firms and their environments, providing a theoretical basis for examining how environmental factors influence servitization. According to RDT, servitization is a strategic response to environmental uncertainty and the need for critical resources. Dynamic environments encourage firms to adopt servitization to enhance adaptability and responsiveness; complex environments require firms to diversify service offerings to meet varied customer demands. Institutional and technological environments also play important roles — government policies and digital advances provide a favorable setting for transformation. Moreover, the influence of the environment is not one-way; firms can also shape and optimize their environments through servitization. This dynamic interaction is central to RDT.

In conclusion, RDT provides a unique lens to analyze the relationship between environmental factors and manufacturing servitization. As external conditions change, firms must continually adjust their resource configurations. J. Zhang et al. (2024) found that the greater the environmental uncertainty, the more likely firms are to pursue servitization to mitigate risk. On a micro level, firm resources and capabilities play key roles during transformation. X. Zhang et al. (2024) confirmed that technological capabilities, marketing strength, and organizational flexibility positively influence servitization. Importantly, the transformation is not a one-way process but a dynamic interaction between enterprise and environment. B. Liu et al. (2016) emphasized that new resources and capabilities gained through servitization feed back into and reshape the external environment, forming a positive resource-environment cycle. Therefore, RDT provides new insights into the drivers and mechanisms behind manufacturing servitization transformation.

2.2.5 Inter-theory linkages

Resource-Based View (RBV), Dynamic Capabilities Theory and Resource Dependence Theory are the theoretical frameworks, which are the basis of the TOE model, providing interlocked views on how technology, organization and the environment influence each other to foster servitization. These linkages are synthesized in this sub-section, where their complementary roles in transforming manufacturing are pointed out.

2.2.5.1 The RBV concept of technological resources of TOE as VRIN asset

The Resource-Based View developed by Barney (1991) gives a theoretical perspective on the reasons why technological resources as part of the TOE view are important in establishing sustainable competitive advantage. RBV assumes that resources that provide a competitive edge have attributes of VRIN that is Value, Rarity, Inimitability, and Non-substitutability.

Value: Digital tools, such as industrial IoT platforms (T. Zhang et al., 2022), AI-powered analytics (Gebauer et al., 2021), or blockchain (Wamba et al., 2022) deliver value by providing predictive services, paying less to operate, and customer intimacy, which are the main goals of servitization.

Rarity: Competitive markets are unlikely to have proprietary technology resources, such as firm-specific data integration systems (Y. Wang et al., 2020), i.e. those developed in-house, which provide some early adopters with an advantage in the market.

Inimitability: cumulatively learned technological capabilities such as an algorithm that a service provider uses to predict its service demand are hard to copy because of path dependence (Acemoglu & Restrepo, 2022).

Non-substitutability: Digital technologies tend to be used to fulfill specific roles in servitization; the IoT sensors cannot be replaced with routine service schedules in facilitating the delivery of services on a real-time basis (Paschou et al., 2020).

In the TOE framework, RBV reasons, technological forces (e.g. electronic infrastructure, organizational technology innovation) are not simply adoption decisions but strategic resources. Companies that utilize VRIN based technological resources are also at an advantage to act on servitization strategy since it is based on these resources that service differentiation and value creation is built on (Barney, 1991; Peteraf, 1993).

2.2.5.2 Dynamic capabilities as the core building block of the organizational fit of TOE

The mechanistic aspect as to how organizations under the TOE framework cope up with servitization is comprised in the Dynamic Capabilities Theory (DCT) developed by Teece (2007). DCT also focuses not only on the ability of a firm to see opportunities, exploit them and recombine resources in fluid settings but also involves several processes that are key to the success of servitization.

Sensing Capability: Organizations are required to identify gaps in the customer demand (e.g. the demand for integrated solutions) and in the advancements of technological solutions (e.g. advancements of IoT). Indeed, the article by Zhan et al. (2022) demonstrates that the most probable drivers of servitization are the firms that possess highly-developed sensing capabilities, including the framework of data-driven market intelligence.

Gaining Capability: After identification of opportunities, companies must spend resources to create service offerings. This involves cross-functional cooperation and quick decision-making such as observed in companies that accelerate in R&D by refocusing it on service innovation (Coreynen et al., 2020).

Reconfiguration of Capability: Servitization frequently entails considerable organisational restructuring of organisations (e.g. flattening of hierarchies (Eggert et al., 2014) or re-training of staff to do service work (W. Xie et al., 2020). Value: The ability to dynamically restructure organizational arrangements and routines is necessary in maintaining service delivery.

Within TOE model, DCT has filled the gap between adoption technology and organizational effectiveness. The servitization of businesses is impossible without dynamic capabilities when the management aims at coordinating processes, structures, and culture with service orientation (Teece, 2007; Zhan et al., 2022).

2.2.5.3 The role of resource dependence theory in environmental responsiveness of TOE

Remarkably, Resource Dependence Theory (RDT) of Pfeffer and Salancik (1978) articulates the interdependent nature of the resources in connection to environmental-related factors of the TOE-based framework and explain their effects on servitization. RDT suggests that organizations rely on external players to provide important resources which influence their strategic approaches towards the environmental factors.

Coercive Resource Dependence: Resource control, such as subsidies or regulatory approvals under the control of the government (J. Zhou, 2024). To be able to use such resources, firms can implement semi-public services (servitization) to have access to them, and it can be observed that policy accompanies digital service efforts in certain regions (B. Zhang & Jin, 2020).

Market Resource Dependence: flows of resources (e.g. revenue on service contracts) are determined by customers and competitors. In super-competitive markets, companies could turn to servitize as a differentiation strategy to gain resource ownership of customers (Q. Huang & Huo, 2014; Yuan et al., 2021).

Network Resource Dependence: The partners of a supply chain offer specialised resources (e.g. digital service providers). Companies can coordinate their servitization initiatives with network partnering to obtain complementary skills as with industrial internet environments (Porter & Heppelmann, 2015).

In TOE, RDT explains why such causes of servitization as environmental factors (e.g., support by the government, competition in the industry) are not passive pores but active forces that drive servitization. The reaction to environmental resource dependencies is the change of service strategies, which means designing services according to the regulatory compliance or copying other successful competitors to gain market resources (Dmitrijeva et al., 2020; Pfeffer & Salancik, 1978).

Combination of RBV, Dynamic Capabilities, and RDT into TOE constitutes a complete picture of intensive servitization research:

RBV: furnishes the analytical basis of technological resources as a source of competition in service delivery.

The Dynamic Capabilities Theory: shows how the adaptability of organizations mediates the innovation of service and the adoption of technology.

The Resource Dependence Theory: provides an explanation of the environmental pressures as one of the triggers of strategic resource allocation to servitization.

The theoretical synergy will allow the researchers to look at how the technological, organizational, and environmental factors do not impact on servitization in isolation, but also dynamically interrelate with each other. To take an example, a firm possessing VRIN technological resources (RBV) can still fail to servitize, because it lacks dynamic capabilities to reconfigure organizational processes (DCT) or risks of resource dependencies in it environment (RDT). Combining these theories, the TOE framework can serve as a sound instrument towards deciphering the intricate machinery behind the manufacturing servitization in digital economy.

2.3 Research hypotheses

2.3.1 Technological dimension

(1) Digital infrastructure

The completeness of digital infrastructure not only impacts social productivity (Bullini et al., 2021), market demand (Audretsch et al., 2015), firms' innovation capacity, and business ecosystem networks (Rong et al., 2015), but is also directly related to the realization of servitization in the manufacturing sector. Guo et al. (2024) point out that digital infrastructure is closely associated with the degree of integration between manufacturing and services. In the context of the rapidly developing global digital economy, digital infrastructure has become a critical indicator of national and regional economic modernization. A well-developed digital infrastructure provides firms with higher-quality digital resources, intelligent operational environments, and more efficient data processing capabilities, thereby optimizing production processes and accelerating industrial transformation and upgrading.

Servitization in manufacturing is essentially driven by modern digital technologies, particularly the industrial internet. Hence, regional disparities in digital infrastructure construction and digital development levels inevitably affect the process of servitization (Pei et al., 2024). Restricted by market environment, factor resources, and policy support, some enterprises may encounter obstacles in servitization due to infrastructure weaknesses (Vendrell-Herrero et al., 2021). Inadequate digital infrastructure and disconnect from international standards increase investment costs in digital services and hinder further improvements in servitization levels (N. Zhou & Bao, 2021).

Digital infrastructure significantly broadens channels for information transmission and acquisition, enhances information accessibility (K. Shen et al., 2023), and effectively reduces service operation costs in manufacturing enterprises (Rong et al., 2021). Investment in digital infrastructure and information technology promotes innovation through digital transformation and improves the level of servitization (F. Wang et al., 2023). Furthermore, enhanced digital infrastructure can alleviate challenges caused by inadequate manufacturing infrastructure, provide data support for business decision-making, improve the quality and efficiency of strategic decisions, and strengthen firms' ability to absorb core international digital services (Y. Gao et al., 2024).

H1: The construction of digital infrastructure can promote the servitization transformation of manufacturing enterprises.

(2) Technological innovation

Technological innovation plays a vital role in promoting enterprise servitization (Eloranta & Turunen, 2016). Manufacturing firms implementing servitization strategies should not weaken their technological innovation capabilities, as this would affect their overall competitiveness and negatively impact their service operations (Benedettini & Kowalkowski, 2022). Technological innovation facilitates the integration and mutual penetration of different industries and sectors, improving the levels of servitization, digitization, and intelligence in manufacturing (H. Zhou et al., 2025). Servitization usually revolves around core products and technologies. Thus, innovation does not compete for resources with servitization but instead creates more opportunities for it (Tongur & Engwall, 2014).

During the transition toward servitization, core technological capabilities play a decisive role. Only by relying on continuous innovation can firms strengthen their competitiveness, develop service-oriented products, improve service quality, and deliver superior customer experiences (J. Wang et al., 2016), thereby providing more personalized, customized, and integrated services to meet evolving customer needs (Cheng et al., 2014), and shifting from product-centric to service-centric business models (Y. Huang et al., 2020).

Product innovation driven by technology can generate new types of services and enhance a firm's overall innovation capacity, enabling the development and delivery of high value-added services such as installation, maintenance, and upgrades (Hwang & Hsu, 2019), which enhance customer satisfaction and loyalty and support the transformation from product orientation to service orientation (Bustinza et al., 2019). At the same time, technological innovation allows firms to adopt service-driven profit models, moving away from traditional product-sales-driven approaches.

With the rise of the digital economy, studies on the interaction between digitalization and servitization have increased, further confirming the positive impact of technological innovation on servitization. Gebauer et al. (2021) argue that servitization results from the integration of services and digital technologies, offering new opportunities for manufacturing transformation. Paschou et al. (2020) suggest that synchronized digital operations enhance service innovation through data analytics. Smart and connected products enable more diverse digital (after-sales) services, thus accelerating the servitization process (Porter & Heppelmann, 2015).

H2: Technological innovation positively promotes the servitization of manufacturing enterprises.

2.3.2 Organizational dimension

(1) Organizational structure

The depth and effectiveness of servitization are significantly influenced by organizational design (Kretschmer & Khashabi, 2020). Organizational design and management are key to the digital and servitization of manufacturing firms (X. Zhang et al., 2024). During the servitization process, the “product + service” business model requires an adaptive organizational structure that responds to customer needs and market changes (Xiao, 2021). In the context of the digital economy, the application of digital technology has brought fundamental changes to business operations, processes, and structures, significantly improving the competitiveness of products and services (Bughin et al., 2019).

As servitization deepens in the digital era, traditional organizational structures can no longer meet business needs. Firms must innovate organizational structures based on the characteristics of their products and services (Gebauer et al., 2005). Structural transformation plays a crucial role in the success of servitization by delivering precise products and services, reducing service uncertainty, and enhancing overall service effectiveness (Mathieu, 2001). Flattened and decentralized organizational structures significantly support the smooth implementation of servitization (Gebauer et al., 2009).

One of the key organizational changes is decentralization. Firms delegate decision-making authority to lower-level departments, encouraging frontline managers to gather and understand market and customer information, allowing experts to design effective service systems and deliver high-quality services. Senior management's empowerment of middle managers is crucial for servitization implementation (Neu & Brown, 2008). Eggert et al. found that decentralized management allows manufacturers to benefit significantly from customer-oriented services, improving the efficiency of servitization (Eggert et al., 2014). Neu and Brown (Neu & Brown, 2005), based on contingency theory and resource advantage theory, found that manufacturing enterprises in dynamic environments with diverse customer needs should adopt customer-oriented strategies and adjust their organizational structures to enable decentralized decision-making.

Driven by digital technology, firms are reshaping business models and processes, prompting organizational restructuring. Some firms have adopted platform-based organizations characterized by “large platforms + small front ends,” shifting from traditional vertical to more flattened structures (Y. Zhang & Li, 2022). Manufacturing firms are also integrating internal resources to implement flatter management models, enhancing flexibility, improving communication efficiency, and streamlining decision-making processes (Mikalef et al., 2018).

This helps reduce internal conflicts during servitization and strengthens coordination between product and service offerings (Zhan & Liu, 2024).

H3: Organizational flattening positively promotes the servitization transformation of manufacturing enterprises.

(2) Human resources

The effective operation of an organization relies on high-quality human capital and sufficient service-oriented personnel. In the digital economy, talent is a core element of the digital ecosystem (Bullini et al., 2021). The servitization of manufacturing requires intensive investment in service-oriented factors such as specialized human resources, which are highly technical, innovative, and knowledge-intensive. These factors enhance firms' competitiveness and innovation capacity (J. Zhou, 2024). Additionally, given the risks and uncertainties of the transformation process, acquiring new technology and talent is especially important (Santamaría et al., 2012).

The constant emergence of new technologies means that firms must recruit digital, R&D, and management talent. This high-quality human capital is essential to achieving successful digital and servitization (X. Zhang et al., 2024). Without sufficient investment in HR and organizational capability, the positive effects of servitization may be diminished (Antioco et al., 2008). In knowledge-intensive sectors, human capital is a vital asset (Pires et al., 2008), and HR investment is crucial for service innovation (Miles, 2001). The lack of qualified personnel severely limits service innovation (Evangelista & Sirilli, 1998; Sundbo & Gallouj, 1998). Firms with more digital talent enjoy stronger production capabilities, better competitive advantages, and greater servitization potential (Y. Chen et al., 2023).

Compared to low-tech innovation, high-tech innovation requires more capital and HR investment. Cities focused on high-tech industries often have more high-quality talent, which gives manufacturing enterprises a significant advantage in servitization (H. Han & Hu, 2024).

In summary, optimizing the structure of human capital is a key path to enabling manufacturing servitization. High-quality personnel are critical drivers of innovation and play a central role in ensuring effective coordination between production and service functions. Servitized manufacturing requires workers with strong knowledge, skills, and capabilities. Improving employee quality and optimizing HR structure are thus fundamental steps in transformation. Moreover, digital technology reshapes labor markets and job structures. Talents with digital literacy and operational skills are vital for innovation and transformation. As smart manufacturing rises, low-skilled jobs are replaced by intelligent systems, while demand for educated labor increases. Thus, firms must strengthen HR training and investment to support servitization in the digital age.

H4: Human resource investment positively promotes enterprise servitization transformation.

2.3.3 Environmental dimension

(1) Government support

Industry environmental characteristics are crucial situational factors influencing enterprise strategic choices and performance outcomes (Porter, 2008). As micro-entities within the business environment, enterprises are inevitably affected by the quality of the policy environment in their respective regions (Deng et al., 2019). A sound policy environment can provide institutional support for manufacturing enterprises to access service factors, thus facilitating the realization of servitization transformation (S. Zhu et al., 2021). Policy and regulatory frameworks have a significant impact on the degree of servitization in the manufacturing sector (Foster & Azmeh, 2020). The government's stance and degree of support toward servitization are essential drivers; a favorable policy environment serves as a key safeguard for manufacturing firms undergoing servitization transformation (J. Zhou, 2024).

Government support refers to the assistance and protection provided by the government during business operations, aiming to compensate for the shortcomings caused by institutional imperfections (Jiao & Tian, 2023). Government support can significantly promote the servitization of advanced local manufacturing industries (Wu & Li, 2023). Measures such as loan provision and special licensing help enterprises reduce operational risks, encourage innovation, and improve performance (J. Zhang et al., 2019). A well-calibrated level of government support is a key driver for enhancing the position in the global value chain and for achieving successful industrial cluster transformation and upgrading (J. Zhang et al., 2019).

Whether firms can obtain effective institutional support directly affects their survival and development (X. Zhao et al., 2022), since all business activities take place within the framework set by government institutions. Institutional support helps enterprises mitigate uncertainty and enhance competitiveness. Especially during the servitization transition period, enterprises can benefit from systematic support and access to policies and resources, thus reducing operational risks and improving performance (Szalavetz, 2020). At the same time, firms in transition can also gain early access to information favorable to transformation (K. Wang, 2024), enabling them to respond proactively to emerging challenges. Therefore, both policy and financial support from the government contribute positively to the servitization of manufacturing enterprises.

H5: Government support promotes the servitization transformation of manufacturing enterprises.

(2) Industry Competition Intensity

The intensity of industry competition reflects the degree of rivalry among enterprises under the constraints of limited market resources (Tsai & Hsu, 2014). When the level of product homogeneity in an industry is high, product substitutability among firms increases, resulting in stronger competition. To avoid fierce rivalry and win consumer preference, manufacturing firms often seek to differentiate themselves by offering unique services, thereby securing greater long-term benefits (Coreynen et al., 2020). Therefore, the intensity of competition is an important factor influencing a firm's intention to pursue servitization. In highly competitive markets, enterprises tend to disrupt the status quo and pursue transformation (Q. Huang & Huo, 2014).

As competition intensifies, firms often face shrinking market shares and declining customer loyalty (Porter, 2008). To remain competitive in such challenging conditions, manufacturing firms must deliver differentiated services to distinguish themselves from competitors, thereby strengthening their market position and improving customer retention (H. Yang & Yu, 2024). This strategic shift from product-centric thinking to a "product + service" model drives firms to prioritize service innovation. As servitization deepens, manufacturing firms increasingly demand productive services and impose higher standards on those services. Enterprises not only need to provide value-added services related to their products but must also regard products as service carriers and eventually position services as their core offering.

In summary, industry competition acts as a major force driving servitization transformation. In highly competitive industries, firms tend to be more proactive in advancing technological innovation and enhancing their service capabilities. Through product iteration and service enhancement, they achieve differentiation (G. Liu et al., 2024). The greater the level of competition in an industry, the higher the likelihood of opportunistic behavior among market players (Yuan et al., 2021). The more intense the competition, the greater the demand for productive service investment and higher service quality requirements—thus driving the upgrading of productive service sectors (J. Li et al., 2023).

H6: Industry competition intensity positively promotes the servitization transformation of manufacturing enterprises.

The theoretical model is shown in Figure 2.2.

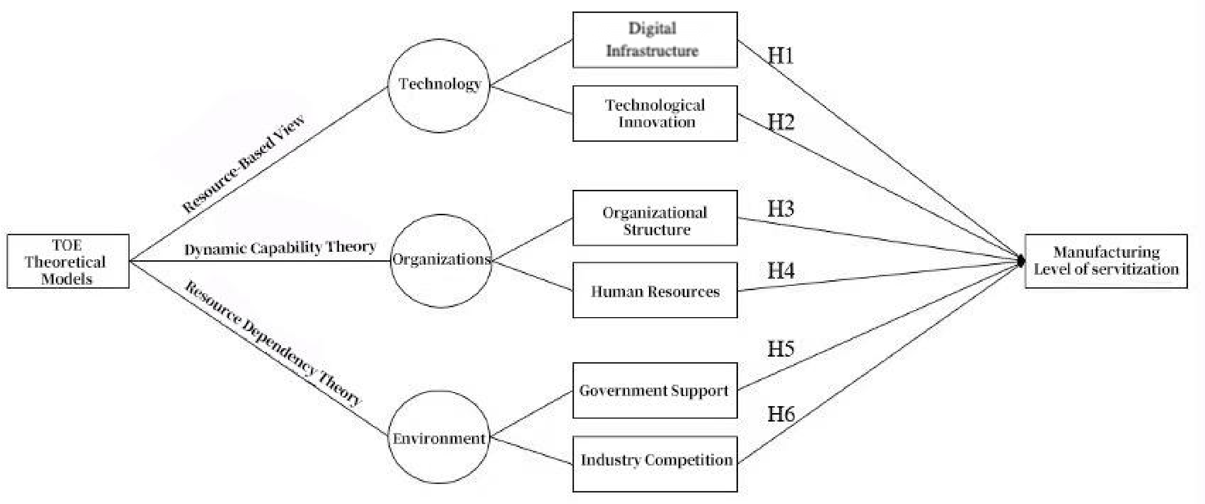

Figure 2.2 Theoretical model and research hypotheses diagram

2.4 Chapter summary

This chapter systematically reviewed literature on the servitization transformation of the manufacturing industry and explored in depth the core concepts and connotations of manufacturing servitization. The transformation towards servitization in manufacturing represents a profound strategic adjustment, involving a shift from a traditional product-oriented model to a service-oriented one. The goal is to meet the increasingly diverse needs of customers through the provision of value-added services and to enhance the core competitiveness of enterprises. Academic research highlights that this transformation is not only the result of technological innovation but also a strategic response by enterprises to adapt to market changes and improve competitiveness.

Firstly, most of the studies provide a static approach through which their analysis is confined to cross-sectional evaluation of the servitization outcomes but not on the evolutionary changes of servitization. Illustratively, although Neely (2008) and Frank et al. (2019) consider the performance consequences of servitization, they seldom consider how iterations of a technological investment and a process of organizational adjustments happen through time. This watchdog provides an adverse contrast to a theory of dynamic capabilities held by Teece (Teece, 2007), which states that servitization entails constant reconfiguration of resources. Another example of digital servitization analysis by T. Zhang et al. (2022) does not pay attention to how service models are modified by firms and adapt to changes in the environment, and thus does not contribute to the understanding of the time aspect of digital servitization.

Second, most studies are extremely location-dependent, and many focus specifically on the

Western economies (e.g., Santamaría et al., 2012) or Chinese setting (e.g., L. Lu et al., 2024). This reduces the ability of generalization, since institutional aspects including the policy regulations and attitudes on service differ considerably among regions. B. Zhang and Jin (2020) show that the institutional quality impacts servitization in China, but few things are understood about the differences in those processes in regions with less-efficient institutions or stronger cultural norms, which makes it harder to develop the universal principles of servitization.

Third, the technological, organizational, or environmental factors used in most studies tend to be isolated, omitting the interactive influence. As an example, Acemoglu and Restrepo (2022) concentrate on technological drivers, whereas Eggert et al. (2014) put an accent on the organizational design, yet only a small number examine how, to borrow a specific word, the digital infrastructure (technological factor) demands the flattened structures (organizational factor) and policy support (environmental factor) to boost servitization (Kohtamäki et al., 2013; J. Zhou, 2024). The simulative capabilities of the TOE framework have not been fully exploited and rarely have studies been conducted regarding moderating influences such as agility in organizations on the connection between technologies and technology-servitization (J. Li et al., 2023) is a partial exception.

A review of the influencing factors of manufacturing servitization reveals that technology, organizational structure, and the external environment are regarded as key elements. The development of digital technology provides the necessary infrastructure and innovative tools for transformation, serving as a major driving force for servitization. At the same time, the optimization of organizational structure is crucial; enterprises must improve internal management efficiency and optimize resource allocation to support the smooth implementation of servitization strategies. The external environment also plays a critical role, especially in terms of government policies and competitive industry environments, which have impacts on the servitization transformation of manufacturing.

Therefore, based on a comprehensive analysis of existing literature on the influencing factors of servitization, this chapter identifies that the key influencing factors align well with the TOE framework (Technology-Organization-Environment). Accordingly, this study adopts the TOE framework to comprehensively analyze how technology, organization, and the external environment interact to promote the shift of manufacturing enterprises toward a service-oriented model. The Resource-Based View (RBV), Dynamic Capabilities Theory (DCT), and Resource Dependence Theory (RDT) provide new perspectives and theoretical support for studying manufacturing servitization within the TOE framework. This chapter elaborates on the importance of technological innovation, optimization of internal organizational resources, and external environmental conditions in driving the transformation toward servitization.

This study fills these gaps in three mutually interconnected ways. The former is theoretical fusion: through a fusion of the TOE construct with the framework of Resource-Based View (RBV), Dynamic Capabilities Theory (DCT), and Resource Dependence Theory (RDT), the latter develops an overall analytical model. RBV gives account of how technology resources (i.e., digital infrastructures) need to be VRIN (Barney, 1991) in order to retain service advantages, whereas DCT theorizes that, how their adaptability (i.e., structural flattenings) mediates technology penetration (Teece, 2007). RDT, in its turn, makes the environmental resource dependencies (e.g. governmental support) relevant to the dimensions of strategic choices (Pfeffer & Salancik, 1978), so that not only the individual factors, but also the synergistic one can be analyzed (e.g. the VRIN technological resources drive the need of dynamic capabilities to adapt to changes in the environment).

The second addition is dynamic view of process. The theoretical model makes it explicit that the concept of servitization can be understood as iterative process the Teece (2007) sensor-seizer-reconfiguring model refers to: based on acquisitions of digital technologies firms (e.g., access to IoT data, (Acemoglu & Restrepo, 2022), businesses sense service opportunities, integrate their resources through organizational capabilities (e.g., cross-functional teams, (Coreynen et al., 2020), and continuously adapt to environmental feedback (e.g., competition, (Yuan et al., 2021). This strategy will avoid the limitation of static analysis by specifying servitization as a process sensitive to situations.

Finally, the research provides an empirical setting. It facilitates context-specific testing because it operationalizes dimensions of TOE with mediating mechanisms, not all of which have yet been identified (Kohtamäki et al., 2013); example of impact of digital infrastructure on servitization: data integration capability). That expands on the cross-context understanding of the effect of such factors as institutional quality (B. Zhang & Jin, 2020) on the connection between technological investment and servitization.

Based on the in-depth analysis of influencing factors across the three dimensions—technology, organization, and environment—this chapter proposes six research hypotheses and constructs the theoretical model of this study. In summary, by reviewing and analyzing existing literature, this chapter clarifies the multidimensional driving forces behind the transformation of manufacturing toward servitization and their interrelationships, thus laying a solid theoretical foundation and framework for the empirical research and policy recommendations in the following chapters.

Finally, this chapter has provided the intellectual landscape of servitization research, identified critical gaps and had a theoretically solid framework around which they occupy these gaps. In combining the variety of theoretical traditions, the focus on dynamic processes, and explicitly allowing contextual analysis, the research is relevant to both understanding the academic literature on servitization mechanisms and offer advice to manufacturing firms. Chapters 4-6 will use this framework as an empirical investigation to shed more light on the interaction of technology, organization, and environment in culminating a successful servitization practice under the digital economy.

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Chapter 3： Methodology

3.1 Research methods

Based on literature analysis, this study constructs a theoretical model and proposes research hypotheses. It uses quantitative methods to test the influence of technology, organization, and environment on servitization. Then, based on the identified influencing factors, it applies the qualitative research method fsQCA to analyze the configuration paths formed by those factors. To address the limitations of fsQCA in necessity analysis, NCA is integrated as a complementary method. Finally, by analyzing typical configuration cases, the study further investigates the practical paths of servitization in manufacturing. The research process and research method are shown in Figure 3.1.

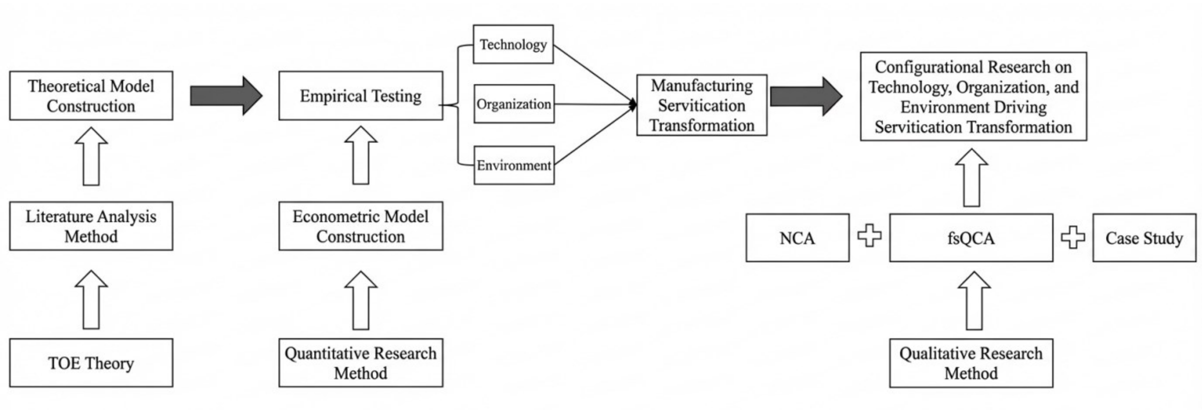

Figure 3.1 Research process and research method

3.1.1 Literature approach

The literature analysis method is the most fundamental and commonly used approach in scientific research. Before conducting any research in a specific field, reviewing, analyzing, and summarizing the existing literature allows us to grasp the progress, theoretical frameworks, research methods, and gaps or shortcomings in that field. As an emerging research area, servitization of manufacturing involves interdisciplinary knowledge and diversified research perspectives, making the application of literature analysis especially important.

On one hand, the literature analysis method helps us deeply understand the core concepts and theoretical models in existing literature. This study systematically reviews and analyzes the key influencing factors of manufacturing servitization through literature analysis, extracting the paths and mechanisms through which these factors affect servitization transformation. Based on the extracted influencing factors, the literature analysis method also provides a solid theoretical foundation for constructing the theoretical model and designing the research framework of this study.

On the other hand, by analyzing a large volume of literature, we can identify previous research achievements and methodologies, determine which research questions remain underexplored or unresolved, and assess the varying importance of factors under different research contexts. This provides guidance for the study’s design and method selection. Additionally, determining how to measure research variables and where to source data also relies heavily on literature analysis. We can summarize measurement indicators, data sources, and research methods used in existing studies to inform our own research, avoid redundancy, and improve efficiency and reliability.

3.1.2 Quantitative analysis method

Building on the literature analysis method, this study employs quantitative analysis to examine the specific impact of technological, organizational, and environmental factors on the servitization transformation of manufacturing enterprises. As a scientific research method, quantitative analysis excels at revealing the relationships between variables in an objective, quantifiable manner, clarifying causal pathways and impact strength, thus offering clear and reliable evidence for research.

Econometric modeling, as a core tool of quantitative research, constructs and estimates mathematical models to analyze socio-economic phenomena, objectively exploring the relationships between them. It allows for precise quantification of variable interactions and helps verify theoretical hypotheses or predict future trends with high empirical and objective value.

In this study, econometric models are used to quantitatively analyze the influencing factors of manufacturing servitization. By building these models, we can clearly and quantitatively express the correlations between technological innovation, organizational elements, external environmental factors, and servitization transformation, providing an objective and comprehensive understanding of the key drivers and mechanisms involved.

To ensure scientific rigor, this study employs statistical software Stata 16 for data processing and analysis. We first conduct descriptive statistical analysis on the collected data related to technology, organization, and environment to understand characteristics such as mean, standard deviation, and range. We then perform correlation analysis to preliminarily explore statistical associations among the variables, use Variance Inflation Factors (VIF) to assess multicollinearity issues, and ensure the normality and homoscedasticity of the residuals.

Next, we construct regression models to empirically test the influence of each factor within the three dimensions—technology, organization, and environment—on manufacturing servitization transformation. To ensure robustness and reliability, we also conduct robustness checks by replacing variables and modifying model forms to test the stability of our regression results.

Through quantitative analysis, this study aims to provide a deeper theoretical and empirical foundation for the servitization transformation of manufacturing enterprises in Shandong Province, clarifying which specific factors play driving roles, and offering targeted, practical policy recommendations for designing and optimizing transformation paths.

3.1.3 fsQCA method

(1) Introduction to fsQCA method

Connection refers to the interactions, mutual influences, and mutual constraints between things or between elements within a thing. It is a principle reflecting the universality and objectivity of material existence. The concept of connection typically manifests as the interaction and influence of multiple factors that together lead to the formation of specific social outcomes—this is particularly evident in the field of management. Numerous studies show that the emergence of a certain result is usually the outcome of multiple interacting conditions (X. Du & Jia, 2017). Similarly, in the practice of enterprise servitization, a successful transformation is also the result of multiple factors interacting and influencing one another.

In 1987 Charles C. Ragin introduced Qualitative Comparative Analysis (QCA) which delivers specific benefits for solving social phenomena with multiple causes (Cai & Zhang, 2023). The research method experienced broad uses during recent years specifically in digital transformation along with organizational performance. The servitization process for enterprises develops through multiple coordinated factors. QCA surpasses linear regression empirical analysis methods by uniting the best characteristics of qualitative and quantitative methodologies for influencing factor analysis. This method analyzes set-theoretical relationships instead of regular correlations by going beyond the assumptions about causal effect consistency. This method proves excellent at discovering multiple pathways leading to similar results thus proving useful for resolving problems related to endogeneity. The research method is suitable for detecting sample heterogeneity while studying both multiple conjunctural causes as well as asymmetric connections in the context of the complex TOE framework and its servitization transformation paths in Shandong Province's manufacturing sector (B. Huang et al., 2021).

QCA is based on Boolean algebra and set theory. It treats each case as a combination of condition variables and aims to identify which combinations lead to the presence or absence of a specific outcome (Ragin, 1987), offering a feasible approach to understanding the multiple causalities behind social phenomena. Rihoux and Ragin (2009) stated that set-theoretic relationships can provide clear and critical insights into explaining complex causal relationships.

The analysis method of QCA differs from regular quantitative research which depends on independent variables and linear associations between elements. Comparsion between cases establishes various causal paths between conditional groupings which either generate target outcomes or leave them lacking. QCA applies a configurational perspective which defeats quantitative constraints regarding single variable effects and multiple causal relationships alongside solving the case study external generalizability problem (Y. Zhang & Li, 2022).

The QCA methods feature three variants which include Crisp-set QCA (csQCA), Multi-value QCA (mvQCA) and Fuzzy-set QCA (fsQCA). CsQCA functions with binary variables which necessitate all variables to be calibrated as either one or zero. Using only binary variables in a QCA analysis might eliminate details from the study which subsequently creates logical inconsistencies between different elements. MvQCA provides an analytical approach for dealing with categorical data factors which have multiple values thus benefiting the examination of multi-varied entities. Crisp-set QCA together with mvQCA depends on truth tables and crisp sets which operate best with categorical data types.

The FsQCA (Fuzzy-set Qualitative Comparative Analysis) method serves as an efficient solution that solves the defects present in both csQCA and mvQCA. FsQCA enables users to set variable calibrations within the 0 to 1 value range instead of binary classification methods while providing membership scores to represent various levels of set membership. The analysis approach of FsQCA operates as both a qualitative and quantitative system to manage categorical along with continuous data elements. The study utilizes both fsQCA and regression analysis to investigate multiple transforming mechanisms that lead to enterprise servitization due to its sophisticated causal origins.

QCA is both a research method and an analytical technique and can be divided into three stages: pre-QCA, QCA analysis, and post-QCA analysis (M. Zhang & Du, 2019). The pre-QCA stage involves condition selection, case selection, and variable calibration. The QCA analysis phase includes necessity analysis, sufficiency analysis, and robustness testing. The post-QCA stage interprets the analysis results and links the findings to existing theoretical contributions (Rihoux & Ragin, 2009).

Unlike traditional quantitative research methods in which data are analyzed directly on the original variables, a necessary and critical step in QCA analysis is the calibration of the variables. The results of calibration directly affect the validity of data analysis and the reliability and explanatory power of empirical results. In this section, based on following the principles of QCA normative analysis, we will specifically describe the operational methods of variable calibration, combining theoretical perspectives and practical research contexts.

(2) Process in fsQCA method

The first step is calibration. According to the QCA process, all collected raw data must be calibrated before conducting set-theoretical analysis, converting them into set membership scores. Technically, calibration refers to the process of assigning membership scores to cases within a set (Schneider & Wagemann, 2013). Transforming raw values into degrees of membership between 0 and 1 is a defining feature of QCA compared to traditional empirical methods.

QCA calibration follows three basic principles: external standards, rationality, and transparency (M. Zhang & Du, 2019).

External standards refer to theoretical and practical knowledge and serve as the primary basis for calibration. Using external standards—rather than relying solely on case data—helps go beyond sample limitations and yields better results (Ragin, 2008). Rationality stems from theoretical relevance and practical validity (Ragin, 1987, 2008) while transparency requires clear documentation and explanation of the calibration process.

From an operational perspective, Ragin proposed three methods of calibration: direct assignment, direct calibration, and indirect calibration.

Direct assignment involves assigning values manually based on variable characteristics and the number of conditions—typically used for qualitative data.

Direct calibration is applied when external standards are lacking; it uses internal distribution features of the data along with logic functions or statistical models. Three qualitative classification elements constitute this approach - complete membership as the first anchor and full non-membership as the second with crossover point as the third anchor. Within the crossover point exactly half of the cases remain undetermined between set membership and set exclusion. The definition of anchors by researchers depends on percentile standards which may include 95th, 50th, and 5th percentiles or 75th, 50th, and 25th percentiles but require theoretical backing and empirical evidence.

Indirect calibration is used when raw data have externally defined reference values, allowing researchers to calibrate variables based on these standards. In practice, data often come from diverse sources—statistical yearbooks, surveys, or case studies—so quantitative and qualitative values may coexist. Therefore, the three calibration methods are not mutually exclusive; researchers may combine them based on research needs. Given the nature of the variables and calibration techniques, different sets in the same study may require distinct calibration types. Regardless of method, calibration must be grounded in theoretical and empirical knowledge. Researchers should justify and document their choices based on prior literature, context, and data characteristics to ensure variables are assigned meaningful membership scores (X. Du & Jia, 2017).

Following the above calibration principles and methods and considering the digital transformation context and data characteristics of this study, the direct calibration method was used to calibrate both outcome and condition variables. Drawing from existing studies on anchor point selection, and considering the data distribution of each variable, the values at the 95th, 50th, and 5th percentiles were used as anchors representing full membership, crossover point, and full non-membership, respectively. This transformed the raw values into membership scores between 0 and 1.

To address ambiguity in cases where membership scores are exactly 0.5 (i.e., maximum ambiguity), which complicates classification, the score was manually adjusted to 0.501 based on precedent in QCA studies to ensure case completeness.

The second step is Necessity analysis. The core of necessity analysis lies in identifying which conditions can be regarded as necessary conditions for a particular outcome, exploring to what extent the outcome set is a subset of the condition set (M. Zhang & Du, 2019). It forms the basis for conducting subsequent sufficiency analysis of condition configurations. In QCA studies, if a condition variable is consistently present whenever the outcome occurs, it can be considered a necessary condition for that outcome. In other words, "without this condition, the outcome cannot occur" (Rihoux & Ragin, 2009). Therefore, the first step in QCA analysis is to test whether each individual condition constitutes a necessary condition for the outcome—namely, to examine whether any of the six factors (digital infrastructure, technological innovation, organizational structure, human resources, government support, and industry competition) independently serve as necessary conditions for the servitization of manufacturing.

This study combines the necessity analysis method of QCA with NCA. Based on standard

QCA necessity analysis, the R 4.4.2 software is used to perform NCA to further test and quantify the degree of necessity of each condition variable. This combined approach also ensures the reliability and robustness of the results presented in this necessity analysis.

In QCA, the necessity of a single condition is typically evaluated through consistency thresholds. Consistency measures the extent to which all cases in the analysis share a particular condition or configuration that leads to the outcome. A higher consistency value indicates that the condition is more likely to be necessary for the outcome. Existing research generally considers a condition necessary when its consistency exceeds 0.9, meaning it can be treated as a necessary condition for the outcome (Schneider & Wagemann, 2013).

Additionally, coverage is another metric in necessity analysis. It reflects the explanatory power of the condition variable and indicates how empirically relevant the condition is for explaining the presence of the outcome. When consistency is greater than 0.9 and coverage is greater than 0.7, the condition can be considered not only necessary but also substantive.

The third step is configuration analysis. Based on necessity analysis, fsQCA 4.1 software's "Truth Table Algorithm" function is used to construct a truth table to analyze the transformation driving patterns of manufacturing servitization, list all possible combinations of conditions and qualitatively explain and name them. Based on the asymmetry of causality, this research analyzes the group paths of high-level and low-level manufacturing servitization, in order to investigate the core factors and paths that promote or hinder the development of manufacturing servitization, to provide a more comprehensive and feasible path for servitization transformation. Based on the Boolean algorithm, the truth table is transformed into a simplified conditional combinatorial path, and the explanatory power of the conditional combinations is assessed by coverage and consistency indicators. The result analysis mainly adopts the Intermediate Solution, combined with the Parsimonious Solution to differentiate between core and auxiliary conditions. Conditional variables appearing in both the Intermediate Solution and the Parsimonious Solution are defined as core conditions, while those appearing only in the Intermediate Solution are regarded as auxiliary conditions, and the complex solution may not be used in this study because it contains too many logical residuals leading to duplicate interpretations (An, 2012).

Finally, robustness testing is a key step in assessing the stability of conditional grouping results and their explanatory power, and is an integral part of QCA research (Schneider & Wagemann, 2013). One of the commonly used robustness tests in existing studies is the pooled theory-specific robustness test, which includes adjusting the calibration threshold, changing the frequency of cases, modifying the consistency threshold, adding other conditions, or excluding cases., and the other is the statistical theory-specific robustness test, such as spanning different time periods, changing the source of the data, or adjusting the measurement method. Given that the results of the fsQCA analysis based on set theory were used in this study, the suggestion of C. Zhao (2021) was referred to, and the set theory-specific robustness test was chosen to verify the robustness of the conditional grouping by adjusting the consistency threshold.

3.1.4 Combination of NCA and fsQCA methods

In management, social sciences, psychology, and education, researchers often use regression analysis, structural equation modeling, and machine learning to explore relationships among variables. However, these traditional methods are based on mean trends and primarily assess the sufficiency of independent variables on outcomes, often neglecting whether certain variables are necessary conditions for outcomes to occur. Necessary Condition Analysis (NCA), proposed by X. Du and Jia (2017) and Y. Du (2019) aims to identify and quantify how necessary a condition is for an outcome to occur.

The basic principle of NCA analysis is that if a variable (X) may be a necessary condition for the occurrence of an outcome variable (Y), then Y will not be able to exceed a particular value if X does not reach a particular level, i.e., although a high value of X may not necessarily lead to a high value of Y, a low value of X may limit the maximum value of Y. Thus, unlike traditional empirical methods, NCA is not concerned with whether a change in X "raises" the level of Y, but rather whether X is a "precondition" for Y to reach a certain level. The core logic of NCA is based on the theory of necessary conditions, i.e., a condition is a precondition for an outcome to occur. If the condition is not met, the outcome cannot be realized no matter how other factors change. Mathematically, the necessity relationship in NCA analysis is "$Y \leq f(X)$", where the function f(X) represents the upper bound of X, which determines the maximum possible value of Y, i.e., if X does not reach a certain critical value Xc, Y cannot exceed a specific level Yc. The necessity analysis method is different from the mean-trend regression equation in regression analysis. , which emphasizes the indispensability of X within a certain range, rather than the average effect on Y.

NCA uses a scatterplot analysis to identify the necessity relationship between X and Y. The relationship between X and Y is a function of the level of necessity. In the X-Y plane, if there is a "vacant zone", i.e., no data point exists in a certain region, it means that X has a necessity effect on Y. NCA determines the magnitude of the necessity effect by identifying the upper bound of the data points, and uses different mathematical methods to estimate the form of the upper bound. The first step in the study of NCA is to draw an X-Y scatter plot based on the data set of X and Y variables to visualize whether there is a necessity relationship between X and Y. The second step is to identify the “vacancy area” and calculate the size of the necessity effect. The second step is to identify the “vacancy zones” and calculate the necessity effect sizes, determine the existence of upper bounds based on the plotted scatter plots, and observe the apparent upper bounds on the Y values in certain regions below the X values. Typically, NCA uses an upper bound regression to fit that upper bound, ensuring that data points do not occur in theoretically impossible regions. The necessity effect size is calculated by the following formula:

$$\mathbf{d=1-\frac{N_{useful}}{N_{total}}} \tag{3.1}$$

$\mathbf{N_{useful}}$ represents the number of observations that satisfy the necessity condition, $\mathbf{N_{total}}$ is the total number of all observations in the dataset, d is the necessity effect, and the higher the value of the necessity effect, the stronger the necessity effect of X on Y is. Finally, the robustness of the NCA results needs to be further tested using Monte Carlo simulation or cross-validation methods to ensure that the identified necessity relationships are not caused by data noise or random distributions.

NCA methods are now widely used in management, education, health sciences, psychology, and other fields. In employee performance research, NCA can be used to identify whether certain key competencies or resources are necessary for high-performing employees, in educational assessment, NCA can be used to analyze the minimum conditions necessary for students to achieve excellent academic performance, and in health research, NCA can identify the necessary conditions for disease prevention. In this research, NCA can be used to identify the factors that are necessary for manufacturing enterprises to achieve high level of servitization. For example, through NCA, it may be found that “human resources” is a necessary condition for “high level of servitization in manufacturing industry”, i.e., if an enterprise does not achieve high level of servitization, it is not necessary for the enterprise to achieve high level of servitization in manufacturing industry. NCA has the advantage of being intuitive and easy to understand, and clearly explains the necessity relationship between variables through the visualization of scatter plots, and its application in this study helps to identify the key bottlenecks of manufacturing servitization that may have been neglected in the traditional mean-trend analysis, so as to help enterprises focus on the real key issues in the process of servitization. The use of fsQCA in this study can help identify the key bottlenecks of manufacturing serviceization that may be overlooked in traditional mean trend analysis, thus helping enterprises focus on the real key issues in the serviceization process, and can effectively make up for the shortcomings of fsQCA research method to further improve the explanatory power of this study.

Although fsQCA is able to identify necessary relationships, it can only provide qualitative judgment on whether a condition is necessary for the outcome, and cannot quantitatively reflect the degree of its necessity, whereas the advantage of NCA lies in its ability to quantify the necessity of a single independent variable for the dependent variable, and at the same time, the drawback of NCA is that it can only identify necessary conditions and cannot analyze complex interaction and causal relationships of multiple variables, so it needs to be combined with other methods. Therefore, the combination of Fuzzy Set Analysis (FSA), which provides more detailed object scores, and Necessary Condition Analysis (NCA), which quantitatively evaluates the degree of necessity of the conditions, (NCA and fsQCA), shows advantages and value in the study of complex causal relationships (Vis & Dul, 2018), the two complementary approaches are highly compatible with the needs of this study, especially in the process of exploring the impact of the six conditions of digital foundation, technological innovation, organizational structure, human resources, governmental support, and industry competition on the outcome of manufacturing servitization under the TOE framework, which need to be assessed for their necessity and adequacy. The use of the NCA research method can effectively make up for the shortcomings of the necessity analysis method in fsQCA, by quantifying the degree of necessity of each of the condition variables to quantify the degree of necessity, thus providing more accurate data support for the emergence of high-level results of manufacturing servitization. Therefore, this study will use a combination of fsQCA and NCA to conduct empirical analysis, giving full play to the respective advantages of these two methods, with a view to comprehensively and deeply understanding the research theme of manufacturing servitization transformation.

3.1.5 Typology

In typological analysis the classification requirements must satisfy two essential conditions: significance and duality. A classification criterion must possess two characteristics: it must represent essential properties of the analysis subject and provide clear detection abilities. The classification standards of duality require them to separate the object into distinct elements (B. Huang, 2018). Research applies the "TOE" model to recognize technology, organization, and environment as fundamental elements representing key internal and external forces that affect manufacturing servitization. The structural standard shows this classification as "inside the organization – outside the organization." This research builds upon TOE principles to analyze manufacturing servitization development models through a three-dimensional examination of technology, organization, and environment which results in a typological triangle framework to support analysis. This study establishes a three-dimensional framework to analyze different servitization transformation patterns for manufacturing companies while performing detailed case assessments. The research presents generalizable patterns of best practices to serve as useful references which guide practical applications.

Analysis of causal mechanisms reveals the precise social processes which explain why certain events occur while improving social science research depth and explanatory capability. The examination of causal mechanisms requires successful completion of two fundamental procedures. The analysis includes both factor identification which influences the process together with building the underlying paths which drive the system. This research focuses on two main elements within its empirical analysis framework. This analysis examines the key determinants affecting manufacturing servitization through identification of decision-making elements. The analysis builds pathways to demonstrate how different elements interface and generate effects that enhance servitization capacity in manufacturing operations.

3.2 Sample selection and data sources

3.2.1 Sample selection

Based on the research theme and prior literature, this study selects manufacturing enterprises in Shandong Province as the research object to explore the transformation path of servitization, focusing on the influence of technological, organizational, and environmental factors in the context of the digital economy.

The reason why the manufacturing enterprises in Shandong Province are taken as the research object is that Shandong Province is one of the core regions of China's manufacturing industry and occupies an undeniable position in the global supply chain and industrial chain, and the manufacturing enterprises in the province cover a variety of industries such as high-end equipment, intelligent manufacturing, chemical industry, automobile, marine engineering. Its manufacturing enterprises not only occupy a position in China, but also still have strong competitiveness and influence in the globally competitive markets. and influence, so studying the servitization of Shandong's manufacturing industry can not only reveal the internal logic of

China's manufacturing upgrading, but also provide a reference for the transformation of the global manufacturing industry (Z. Chen & Chen, 2025).

Second, in the context of the digital economy driving the global manufacturing transformation, Shandong possesses cutting-edge practices in the integration of digital technology and servitization transformation. The global manufacturing industry is entering a new stage of digitalization, intelligence and service integration, and Germany's “Industry 4.0”, the United States' “National Strategy for Advanced Manufacturing”, and Japan's “Society 5.0” all emphasize the role of digital technology in the transformation of the global manufacturing industry. Shandong Province, as a major manufacturing town in China, has made certain breakthroughs in the fields of artificial intelligence, industrial internet, and big data, and has extensively explored the digital transformation of manufacturing (B. Chen, 2021; Y. Wang et al., 2025). Therefore, studying the path of servitization transformation of manufacturing enterprises in Shandong is in line with the global trend of servitization in the digital era, and helps to build a theoretical framework and practical experience for global manufacturing transformation.

Third, the servitization of Shandong's manufacturing industry is closely related to the improvement of international competitiveness. As the global manufacturing industry shifts from “product-oriented” to “service-oriented”, manufacturing enterprises are enhancing their market competitiveness through the provision of value-added services (e.g., intelligent operation and maintenance, personalized customization, remote monitoring (Luo & Liu, 2024). Manufacturing firms in Shandong Province are accelerating this process, and their servitization transformation not only helps to enhance their competitiveness in the global market, but also provides a model for the overall upgrading of China's manufacturing industry (Y. Zhu & Yu, 2024). Therefore, from the perspective of international competition, the path of servitization of Shandong's manufacturing industry deserves in-depth study. Fourth, the diversity of industrial structure of Shandong's manufacturing industry fits with the global manufacturing trend. The trend of digitalization and servitization transformation of global manufacturing industry is not limited to a certain industry but covers multiple fields. Shandong's manufacturing industry has a diverse structure, including traditional industries such as machinery manufacturing, chemicals, and iron and steel, as well as emerging industries such as high-end equipment, new energy, and new materials. The diversity of its industries makes Shandong an ideal case for observing how different manufacturing industries can achieve servitization transformation.

3.2.2 Data sources

Based on the aforementioned reasons, the research object of this research is Shandong Province, China, given that the focus of this study is on the study of factors affecting the servitization of the manufacturing industry, rather than the changes in the servitization of the manufacturing industry over time, the sample of this study selects the manufacturing enterprises in the A-share listed companies in Shandong Province in 2023, and excludes the poorly operated ST and *ST listed Enterprise samples and operating profit is negative samples, and samples with significant missing data, data are from the A-share listed companies financial statement data, CSMAR database, which for digital infrastructure, some enterprises' number of undergraduate employees, and government subsidy amounts missing data, this study uses the extrapolation method based on the values of the preceding five years to fill the gaps. After screening and organizing the sample data, this study finally constructs a database covering 102 enterprises in the year 2023, involving six variables, and the specific treatment and measurement methods of each variable will be elaborated in the variable description section in the next section.

Note: ST" in listed companies stands for "Special Treatment." It is a label given to companies that face financial difficulties or other abnormal situations, such as consecutive years of losses, to warn investors of potential risks.

3.3 Variable description and econometric model

The measurement and collection of variables are directly related to the scientific rigor and reliability of research findings, making them a crucial component of empirical studies. This section defines and measures the dependent variable and conditional variables. Based on the clarification of variable operationalization, a regression model is further established to ensure analytical rigor and precision.

3.3.1 Variable selection

3.3.1.1 Dependent variable

The dependent variable of this study, as well as the dependent variable in the QCA analysis, is the servitization transformation of manufacturing enterprises. Drawing upon the work of Neely (2008), Homburg et al. (2002), and J. Li et al. (2015), this study integrates and extends measurements of servitization levels. The servitization of manufacturing enterprises is measured from two dimensions: service quantity and service depth.

In terms of servitization level, this study primarily adopts the measurement method used by Neely (2008) and J. Chen (2010), treating the number of services provided as a core indicator. Services are categorized into ten types:

(1) Basic product services (e.g., repair, maintenance, installation, inspection),

(2) Consulting and training services,

(3) Leasing services,

(4) Operational outsourcing and engineering services,

(5) Sales services (including distribution, wholesale, retail, and international trade),

(6) Financial services (e.g., financing support for customers and distributors),

(7) Agency services,

(8) Software development and platform services,

(9) Design services (e.g., integrated solution design), and

(10) Logistics and transportation services.

Considering the differences in the nature and depth of various services, for instance, common after-sales services (such as repair, maintenance, installation) differ significantly in depth from integrated solution services, the latter involves a higher level of service depth. Therefore, based on service quantity, this study applies a weighted treatment. Referring to J. Li et al. (2015) and integrating the service model classifications of Neely (2008), Sun et al. (2008), and An (2012), service models are divided into three types based on the stages of service development within manufacturing enterprises:

- Product-oriented extended services**,**
- Solution-oriented integrated services**,**
- Application-oriented functional services

Weights of 1, 2, and 3 are assigned to these three categories, respectively, as depth coefficients to address limitations in the measurement metrics of Neely (2008) and J. Chen (2010). The specific connotations of these classifications are shown in Table 3.1. Based on this classification, service quantity is weighted to ultimately calculate the level of servitization. The measurement formula for servitization level is as follows:

$$\mathbf{Ser_m = \Sigma(Q_{im} \times D_{jm}), (i \in [1, 10]; j \in [1, 3]; m \in [1, 208])} \quad (3.2)$$

where Ser_m represents the level of servitization of the m-th manufacturing enterprise, S_i indicates the servitization level of the i-th manufacturing enterprise; Q_{im} represents the number of services provided by the m-th manufacturing enterprise (based on the 10 service categories mentioned above); D_{jm} represents the service depth of the m-th manufacturing enterprise (based on the 3 levels of service depth classification described earlier).

Table 3.1 Classification of service models in manufacturing enterprises

Service Model	Connotation	Specific Content
Product-Extended Services (Focused on Product)	The ownership of the physical product belongs to the customer. The enterprise provides additional value-added services based on the physical product, and the services provided are directly related to the product.	Warranty, repair, equipment installation and commissioning, maintenance services, logistics services, retail and distribution services.
Integrated Solutions (Focused on Solution)	Based on tangible products, a comprehensive solution that integrates products and services is provided to meet customers' differentiated needs.	Customized product design, basic solution provision, consulting and training, financial services, design and development services
Functional Services (Focused on Application)	The ownership of the physical product is not transferred; the enterprise provides customers with the right to use the product for a certain period or directly provides related services to realize the product's utility.	Leasing, operation outsourcing services

Note: This table is adapted from J. Li et al. (2015).

3.3.1.2 Conditional variables

Starting from the TOE theoretical framework and incorporating specific theoretical analyses, this study sets six conditional variables for regression analysis. These include digital infrastructure and technological innovation under the technological dimension, organizational management efficiency and human resources under the organizational dimension, and government support and industry competition under the environmental dimension. Drawing on existing research, the study provides clear definitions of each variable to ensure operability. For variables that are difficult to measure directly or for which data is limited, the study refers to commonly used academic methods and selects appropriate proxy variables to ensure the scientific rigor and feasibility of the study.

The evaluation indicators of each variable are shown in Table 3.2.

Table 3.2 Evaluation indicators of variables

Dimension (TOE)	Conditional Variable	Variable Description	Evaluation Indicator
Technology (T)	Digital Infrastructure (DI)	Level of digitalization	"Internet+" Digital Economy Index of the city where the firm is located
	Technological Innovation (TI)	Innovation input	Ratio of R&D expenditure to operating revenue
Organization (O)	Flat Structure (FS)	Organizational flatness	Ratio of senior executives to total number of employees
	Human Resources (HR)	Human resource structure	Proportion of employees with bachelor's degrees or above
Environment (E)	Government Support (GS)	Government subsidies	Natural logarithm of the amount of government subsidies received by the firm

Dimension (TOE)	Conditional Variable	Variable Description	Evaluation Indicator
	Industry Competition (IC)	Herfindahl-Hirschman Index	$HHI=\Sigma_{i=1}^{N}(\frac{S_i}{S})^2$

(1) Digital infrastructure

In the era of digital service economy, the boundaries between traditional manufacturing, commerce, logistics, and finance are becoming blurred. Digital data, digital technologies, and digital infrastructure have become the core driving forces of digital servitization transformation (B. Huang et al., 2021). Based on the characteristics of this study and previous measurements of digital infrastructure (Hustad & Olsen, 2021; Nambisan, 2017), this study adopts the "Internet Plus" Digital Economy Index published by Tencent Research Institute to measure the regional level of digital infrastructure. The "Internet Plus" Digital Economy Index is a comprehensive index composed by multiple sub-indices. On one hand, it evaluates the operating scale of major digital platforms to reflect the production and supply capacity of local digital technologies and support services. On the other hand, it uses the number of Internet users as a metric to represent local market demand. Additionally, it assesses the level of digital governance of local governments, thereby measuring the local trust mechanisms (J. Yu et al., 2021). Through this multi-dimensional assessment, the index can accurately reflect the level of digital infrastructure across different regions.

(2) Technological innovation

Existing literature mostly measures technological innovation from input or output perspectives, using data such as patent ownership, new product sales revenue, number of patent applications, new product output, and R&D expenditure (Y. Wang et al., 2025; Xu et al., 2025; Q. Yang & Zhou, 2019). However, these output indicators have certain limitations in measuring enterprise innovation. For instance, patent counts may be influenced by government policies, patent expiration, and patent transfers. New product sales revenue can be affected by pricing strategies, marketing, and competition, making it difficult to accurately measure the level of technological innovation. Furthermore, many firms do not rely on patent applications to protect R&D results, but instead maintain technical advantages through internal confidentiality, making it difficult to use patent-related metrics as effective proxy indicators of innovation (B. Zhang & Jin, 2020). Overall, given the high uncertainty and randomness of innovation outcomes and returns, relying on output indicators alone cannot accurately reflect a firm's stable level of innovation.

Therefore, this study adopts input-based indicators. R&D expenditure, as a key resource of enterprises, can reflect the sustainability of technological innovation. Thus, this study measures technological innovation by the ratio of total R&D expenditure to operating revenue. This approach not only assesses innovation enthusiasm from the input perspective but also helps ensure the empirical analysis accurately reflects the long-term impact of servitization on technological innovation.

(3) Organizational structure

The number of managerial levels in an organization is typically used to assess the degree of structural flattening. Fewer levels suggest a more flattened structure. A key feature of flattening is the reduced proportion of middle managers, implying more efficient decision-making and information flow. However, due to difficulties in obtaining data on middle management, this study uses the ratio of senior management to total employees to reflect structural flattening. This ratio directly reflects the degree of flattening in enterprise decision-making and can effectively evaluate the flexibility of organizational structure (Zuo & Liu, 2024).

(4) Human resources

An organization is a collective of two or more individuals working together toward a common goal. Talent is the most fundamental and core element. The structure of human resources is a critical component of the organizational structure. In Lucas's (1988) human capital spillover model, the spillover effect can be explained as learning from or with others. Individuals with high human capital can positively influence those around them, improving organizational productivity and service efficiency, thus promoting servitization. As a key input in the production process, human resources influence overall efficiency and competitiveness, making them a key driver of servitization in manufacturing. The proportion of employees with bachelor’s degrees or higher reflects the general education level of staff. A higher educational level implies stronger learning and innovation capabilities and better reflects the quality and structure of human capital. Therefore, this study uses the proportion of employees with a bachelor’s degree or higher to assess the impact of human resources on servitization.

(5) Government support

Government support for enterprises varies significantly in content and form and can change with the economic environment, policy shifts, and social needs. Therefore, it is not a static action but a dynamic process that adapts to changes in the external environment. Previous studies have shown that proxy variables can effectively reflect the degree of government support for enterprise strategy (Y. Yang et al., 2015). The amount of subsidies received by firms reflects the strength of government support for specific enterprises or industries. Thus, researchers typically use the amount of government subsidies as a proxy to measure support intensity (Cai & Zhang, 2023; J. Wang & Li, 2024). To more precisely evaluate the impact of government support on servitization strategies, this study uses the natural logarithm of government subsidies disclosed in financial reports as the measurement indicator. The logarithmic transformation smooths volatility, gives the variable proportional meaning, and better captures the relative strength of government support. The higher the value, the greater the support received by the enterprise (Y. Wei et al., 2024).

(6) Industry competition

Industry market competition (IMC) measures the intensity of competition faced by firms. Existing research agrees that market competition significantly impacts servitization strategies (X. Zhang et al., 2024). In fiercely competitive environments, firms tend to accelerate servitization to seek new sources of profit (Q. Huang & Huo, 2014). Although there is no universally accepted metric, the Herfindahl-Hirschman Index (HHI) is widely used to evaluate market competition intensity. This study adopts HHI, defined as the sum of squared revenue shares of all firms in an industry (Qi & Ge, 2022). This study classifies industries based on the first two digits of the 2012 version of the industry classification standard issued by the China Securities Regulatory Commission. The formula for calculating the Herfindahl-Hirschman Index is:

$$\mathbf{HHI}=\sum_{i=1}^{N}\left(\frac{S_i}{S}\right)^2 \tag{3.3}$$

In the calculation of the Herfindahl-Hirschman Index (HHI), N represents the number of listed companies within the industry, while S_i denotes the proportion of firm i's annual operating revenue relative to the total operating revenue (S) of the industry in that year. When industry competition intensifies, the revenue differences among firms become smaller, resulting in a lower HHI value.

3.3.1.3 Control variables

The study reduces the risk of omitted variable bias through inclusion of multiple essential control variables as identified in existing research for a complete analysis of servitization factors in manufacturing firms. The research includes three key control variables which measure years since listing together with enterprise size and business performance to achieve results reliability. There are specific definitions and operational methods which provide the following details:

(1) Years since listing. Enterprises with a longer listing history have typically undergone more market cycles, possessed stronger risk resistance, and had greater experience adapting to market environments, which may affect their decision-making and execution capacity in the servitization transformation process. Therefore, the impact of listing years on manufacturing

servitization should not be ignored. In this study, the number of years since listing is calculated by subtracting the year of listing from the current year. For example, if Weichai Power Co., Ltd. was listed in 2007, its listing age in 2023 would be 16 years; for Qingdao Sanbaishuo Health Technology Co., Ltd., which was listed in 2022, its listing age in 2023 would be 1 year; if a company was listed in 2023, its listing age in 2023 would be 0 years.

(2) Enterprise size. Larger enterprise size often reflects advantages in high-quality human capital, advanced production technologies, and capital accumulation, which are beneficial for enhancing transformation capabilities. To measure firm size, this study uses the number of employees at year-end as an indicator and applies logarithmic transformation to the data.

(3) Enterprise performance. One of the main motivations for enterprises to adopt a servitization strategy is declining operating profits or increasing pressure from the external environment, prompting strategic adjustment (Xiao, 2021). From an investment perspective, better-performing firms have more resources available during transformation and are more capable of exploring new business areas. Therefore, business performance is considered a key factor influencing whether an enterprise engages in manufacturing servitization. This study uses the sales profit margin to measure enterprise performance.

3.3.2 Model specification

The model will use the data of 102 manufacturing enterprises in Shandong in 2023 to construct a regression econometric model to conduct an empirical analysis of the factors affecting the service-oriented manufacturing industry. This research takes the service-oriented manufacturing industry as the dependent variable, digital foundation, technological innovation, organizational structure, human resources, government support and industry competition pressure as independent variables, and enterprise survival years, enterprise scale and enterprise performance as control variables. Based on the theoretical analysis and research hypotheses in the previous article, the following benchmark model is set to test the relationship between digital foundation, technological innovation, organizational structure, human resources, government support, industry competition pressure and the service-oriented manufacturing industry:

$$\textbf{Servitization}=\alpha_0+\alpha_1\textbf{Digital Infrastructure}+\alpha_2\textbf{Tech Innovation}+\alpha_3\textbf{Flat Structure} +\alpha_4\textbf{HR}+\alpha_5\textbf{Gov Support}+\alpha_6\textbf{Industry Competition}+\alpha_7\textbf{CONTROL}+\varepsilon \tag{3.4}$$

In the above models, Servitization denotes the level of manufacturing servitization; Digital Infrastructure represents the level of digital infrastructure; Tech Innovation refers to technological innovation; Flat Structure reflects the degree of organizational flattening; HR indicates the firm's investment in human resources; Gov Support refers to government support received by the enterprise; Industry Competition captures the competitive pressure in the industry; and CONTROL denotes the group of control variables (firm age, firm size, and firm performance).

Identifying the development paths of local manufacturing servitization is key to exploring the causal mechanisms behind it. This chapter includes two main parts. First, based on the analysis of servitization influencing factors in the previous chapter, it incorporates variables into a qualitative comparative analysis using the fsQCA method to examine the servitization transformation paths of manufacturing firms in Shandong in 2023, revealing the multiple driving mechanisms behind the shift.

Second, under the TOE framework and guided by the interaction logic between digital technology, internal organization, and external environment, it constructs a typology of different development paths to summarize various modes of manufacturing servitization. By integrating qualitative and quantitative methods, this chapter aims to provide a more comprehensive and understanding of the complex causal mechanisms of local manufacturing servitization.

3.4 Chapter summary

The current chapter outlines methodological framework that will be used to explore the topic of servitization shifts of manufacturing companies, which would incorporate elements of both quantitative and qualitative approaches into the theoretical framework of TOE. The research steps would include literature analysis as a foundation to develop a theoretical framework and determining the influential factors, as well as quantitative regression analysis, in which Stata 16 could be applied to evaluate the effect of technological, organizational, and environmental factors on servitization. Fuzzy-set Qualitative Comparative Analysis (fsQCA), presenting complexity of causal relationships, is used to determine them, which involves calibration of variables, necessity and configuration analysis to reveal a number of pathways leading to servitization. fsQCA is inbuilt with Necessary Condition Analysis (NCA), this is used to measure the degree to which the individual conditions are necessary, which complements the qualitative evaluation of this methodology.

The sample of the study selects 102 manufacturing enterprises with the A-share market in Shandong Province in 2023, where the ST and ST firms are excluded, using the information in the financial statements and the Cathay Pacific database. Servitization level is a dependent variable and is measured by multiplying the quantity of services (10 categories) with the level of service depth (3 levels: product-oriented, solution-oriented, functional services). Conditional variables refer to digital structure (Tencent Internet Plus Index), technological innovation (R&D spend ratio), organizational flatness (ratio of senior management to employees), human resource (proportion of bachelor's degree), government facilitation (log of subsidies) and industry rivalry (the Herfindahl Hirschnum Office). The controls are years of listing, the size of the firm (log of employees) and performance (sales profit margin). Servitization as the outcome variable is defined using these variables, and robustness tests are carried out so that the results are not sensitive. This consortium-type research entails quantitative regression, configure analysis and case typology as complimentary procedures to advance the study of servitization processes and trajectories.

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Chapter 4: Data Processing and Analysis

4.1 Data analysis and results

4.1.1 Descriptive analysis

Table 4.1 presents the descriptive statistics of each variable. Due to the large values of the variables on government subsidies and firm size, natural logarithm transformations were applied to minimize potential heteroscedasticity issues. As shown in Table 4.1, there is considerable variation between the dependent variable and each of the condition variables. Meanwhile, the average value of manufacturing servitization is 3.1961, with a standard deviation of 2.6515 and a range of 14, indicating differences in servitization levels among manufacturing enterprises in Shandong Province. This suggests that the development across the region remains uneven. In addition, the observed differences across the statistical samples imply that the data have good variability, which is beneficial for the subsequent regression analysis.

Table 4.1 Descriptive statistical analysis results

Variable	Sample Size	Minimum	Maximum	Mean	Std. Dev.	Median
Servitization Level	102	1.0000	15.0000	3.1961	2.6515	3.0000
Digital Infrastructure	102	207.8180	323.0210	259.0683	32.2276	247.2050
Technological Innovation	102	0.0033	0.0887	0.0416	0.0176	0.0416
Organizational Structure	102	0.0111	4.6053	0.4056	0.5364	0.2536
Human Resources	102	0.1800	52.0300	20.4155	11.3632	17.4350
Government Spending*	102	12.8795	20.6647	16.4034	1.5695	16.4069
Industry Competition	102	0.1152	1.0000	0.3362	0.2346	0.2797
Firm Age	102	0.0000	27.0000	10.8824	8.4059	8.0000
Firm Size*	102	5.0239	11.3068	7.7709	1.0782	7.7692
Firm Performance	102	0.0030	0.5335	0.1144	0.0914	0.0903

Note: *Values expressed in natural logarithm form.

4.1.2 Correlation analysis

Before conducting regression analysis, this study performed a correlation analysis among the variables. As shown in Table 4.2, the table presents the correlation matrix among all variables. The results indicate that there are positive correlations ($p < 0.05$) between each of the conditional variables and the dependent variable—manufacturing servitization. Moreover, based on Pearson correlation coefficients, no values were found to exceed 0.8, which preliminarily suggests that there is no serious collinearity issue.

Table 4.2 Pearson correlation matrix

	Mean	Std. Dev.	ser	di	ti	fs	hr	gs	ic	a	size	p
ser	3.1961	2.6515	1									
di	259.0683	32.2276	0.0020	1								
ti	0.0416	0.0176	0.2559**	0.1045	1							
fs	0.4056	0.5364	0.1003	0.3658**	0.1475	1						
hr	20.4155	11.3632	0.3348**	0.1033	0.1852	0.0163	1					
gs	16.4034	1.5695	0.2690**	-0.2829**	0.2290*	-0.4566**	0.1665	1				
ic	0.3362	0.2346	0.1667	-0.0333	-0.0982	-0.1039	0.0344	0.0645	1			
a	10.8824	8.4059	0.1565	-0.7150**	-0.1967*	-0.4033**	0.0867	0.3258**	0.0912	1		
size	7.7709	1.0782	0.0477	-0.4567**	-0.0000	-0.6485**	0.0001	0.6971**	0.0134	0.5346**	1	
p	0.1144	0.0914	-0.1716	0.2039*	0.1756	0.0952	0.1998*	-0.0810	-0.0080	-0.0874	-0.1348	1

Note: * p < 0.05, ** p < 0.01.

To further eliminate the potential influence of multicollinearity on the regression results, the variables were input into the regression model and tested using Variance Inflation Factor (VIF) analysis. As shown in Table 4.3, all VIF values were below 10, and all tolerance levels were greater than 0.1. Therefore, it can be preliminarily concluded that there is no serious multicollinearity among the conditional variables, and the regression model estimation can proceed.

Table 4.3 Multicollinearity diagnostics

Variable	VIF Value	Tolerance
Serv	1.5712	0.6365
DI	2.3707	0.4218
TI	1.3883	0.7203
FS	1.9029	0.5255
HR	1.2837	0.7790
GS	2.4286	0.4118
IC	1.0808	0.9253
A	2.8633	0.3492
Size	3.2504	0.3077
P	1.2542	0.7973

Note: Serv = Servitization Level; DI = Digital Infrastructure; TI = Technological Innovation; FS = Organizational Structure; HR = Human Resources; GS = Government Spending; IC = Industry Competition; A = Firm Age; Size = Firm Size; P = Firm Performance.

4.1.3 Regression analysis and results discussion

Based on OLS regression analysis, this study examines the effects of digital foundation, technological innovation, organizational structure, human resources, government support and competitive industry pressure on manufacturing servitization by constructing the model in the previous section, and the results of empirical analysis are shown in Table 4.4. In general, the closer the R-squared value is to 1, the better the model fits the data. However, a lower R-squared value does not necessarily mean that the model is invalid, especially in the field of social sciences or economics, where the relationship between explanatory variables is usually more complex and variable. The R-squared value of 0.3635 in this regression model is mainly because manufacturing servitization is a complex phenomenon involving multiple factors, and its changes may be influenced by many factors that cannot be directly considered in the model (e.g., market demand, globalization.). Therefore, even though this model includes multiple independent variables, it is still unable to capture all the influencing factors, resulting in an R-squared value below 0.5.

Table 4.4 Basic regression results analysis

Variable	Model 1
Digital Infrastructure	0.0177* (1.71)
Technological Innovation	34.9026** (2.44)
Organizational Structure	1.0035** (1.80)
Human Resources	0.0556*** (2.62)
Government Support	0.4885** (2.29)
Industry Competition	1.7738* (1.85)
Firm Age	0.1169*** (2.74)
Firm Size	-0.4008 (-1.09)
Firm Performance	-8.3613*** (-3.27)
Constant	-10.1946** (-2.44)
R^2	0.3635

Note: Values in parentheses are t-values. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

The analysis results of Table 4.4 show: First, digital infrastructure is significantly and positively correlated with manufacturing servitization at the 10% level. For every 1% improvement in digital infrastructure, manufacturing servitization increases by 0.0177 percentage points. The main reasons are twofold:

Firstly, remarkable advancements in spatial and temporal coverage, stakeholder participation, and real-time interactivity have made digital infrastructure a carrier for data collection, storage, and circulation. This effectively eases the data bottlenecks faced in the process of manufacturing servitization and expands the depth and breadth of customer-side data in enterprise value creation. Through digital network platforms, enterprises can automatically collect every aspect of consumer online behavior, such as click patterns, time spent on pages, and product bookmarks. This not only reduces the cost of obtaining user information for producers (K. Xie et al., 2016), but also facilitates a shift in the manufacturing model from producer-led to consumer-driven, thus enhancing the level of enterprise servitization (Turner et al., 2020; Yan et al., 2020). In addition, the application of Internet of Things (IoT) technology enables enterprises to obtain real-time operational data throughout the product lifecycle and conduct status modeling and dynamic tracking. This allows firms to provide value-added services such as quality monitoring, preventive maintenance, product upgrades, and recycling. It enhances lifecycle management and optimizes service models, thereby further elevating the level of servitization. Hypothesis H1 is validated.

Secondly, technological innovation is significantly and positively correlated with the servitization of the manufacturing industry at the level of 5%, and every 1 percentage point increase in technological innovation will bring about a 34.9026 percentage point increase in the servitization of the manufacturing industry. With the development of advanced technologies such as artificial intelligence, big data, cloud computing and the Internet of Things, manufacturing enterprises are able to more effectively integrate resources, improve production efficiency and provide more accurate personalized services, thus promoting the transformation of the manufacturing industry from pure product production to the "product + service" mode and accelerating the process of manufacturing services. On the other hand, technological innovation has enhanced the flexible manufacturing capability of enterprises, enabling them to respond faster to changes in market demand. The application of intelligent manufacturing technology enables enterprises to monitor and optimize the production process in real time and quickly adjust the production plan when customer demand changes, and this flexibility enhances the service attributes of the manufacturing industry, enabling enterprises to provide customers with customized and personalized products and value-added services. In addition, technological innovation reduces the cost of manufacturing enterprises' transformation to services, enabling them to acquire, analyze and utilize data at lower costs, optimize production and service links, and more easily carry out data-driven services based on data, thus facilitating the expansion of servitization in the manufacturing industry. Hypothesis H2 is verified.

Thirdly, organizational structure and manufacturing servitization are significantly and positively correlated at the 5% level, and every 1 percentage point improvement in organizational structure will bring about a 1.0035 percentage point increase in manufacturing servitization, reflecting the facilitating effect of organizational structure optimization on manufacturing servitization, and Hypothesis H3 is verified. Further analysis of the reasons lies mainly in the fact that the optimized organizational structure can improve information flow and decision-making efficiency. With the development of information technology and the increasing complexity of the market environment, manufacturing enterprises are facing higher operational pressure, especially in the process of servitization. Enterprises need to respond quickly to changes in market demand, and a streamlined hierarchical structure and more flexible management mode are the key to the rapid response of enterprises to market changes. By reducing the number of management levels, the decision-making process becomes more efficient, reducing the time for information transfer and friction between levels, which in turn enhances the enterprise's adaptability in the face of dynamic markets. At the same time, efficient organizational operations provide a stronger intrinsic driving force for the transformation of the manufacturing industry into a service-oriented one. As the market demand for customized and personalized services increases, it is difficult for manufacturing enterprises to respond quickly to these changes if they rely on the traditional organizational structure, while the optimized organizational structure enables enterprises to more flexibly adjust the allocation of resources and the development process of products and services, to better respond to customer demand.

The optimization of the organizational structure not only promotes the improvement of production efficiency but also injects a strong innovation impetus into the enterprise, and promotes the transformation from pure manufacturing to manufacturing + service mode.

Fourth, human resources and manufacturing servitization are significantly and positively correlated at the 1% level, and every 1 percentage point improvement in human resource structure brings 0.0556 percentage point increase in servitization of manufacturing enterprises, and hypothesis H4 is verified. Further analysis of the reasons may lie in the fact that the optimization of human resource structure can improve the innovation ability and service quality of enterprises. With the continuous progress of technology and the intensification of market competition, the demand for high-quality, multi-skilled composite talents in manufacturing enterprises has become more and more urgent, and high-end talents are not only able to improve production efficiency and optimize the production process, but also able to play an important role in the field of service innovation, customer relationship management., and promote the transformation of the enterprise from the traditional manufacturing to the more value-added services. In addition, by strengthening human resource management, especially investing in employee training, skills upgrading and incentives, enterprises can help their employees better adapt to the rapidly changing market demand. In a highly competitive market environment with rapid technological updates, continuous employee training and incentive policies can ensure that employees are equipped with the latest technological capabilities and service awareness, to better meet the individual needs of customers. For example, cross-departmental collaborative training and an innovation-driven work environment help to stimulate employees' creativity and problem-solving abilities, which are essential for enhancing the added value of products and services. Further, an optimized human resource structure can enhance the enterprise's responsiveness to market demand, and through the rational allocation of human resources, the enterprise can develop in parallel in multiple fields and quickly adapt to dynamic changes in the market. Therefore, the rational and flexible allocation of human resources can enable manufacturing enterprises to better provide customized and personalized services in a competitive market, meet the specific needs of different customers, and provide Customers to provide value-added services, and thus promote the process of servitization.

Fifth, government support is significantly and positively correlated with servitization of manufacturing enterprises at the 5% level, and every 1 percentage point increase in government support brings 0.4885 percentage point increase in enterprise performance, reflecting the facilitating effect of government support on the servitization transformation of manufacturing enterprises, and hypothesis H5 is verified. Further analyzing the reasons, there are 2 main points:

first, the government provides policies such as capital subsidies, tax incentives and innovation rewards can effectively reduce the financial pressure faced by manufacturing enterprises in the process of servitization. The realization of servitization usually requires enterprises to invest a large amount of capital to update technology, improve production processes and provide higher value-added services, while the government reduces the financial burden of enterprises through subsidies and incentives so that they can increase their investment in technology research and development, service innovation and other aspects, thus to a certain extent promoting the progress of the service-oriented enterprises. Secondly, government policy support provides a more stable and predictable business environment for enterprises, which not only helps them to solve financial bottlenecks, but also plays the role of information orientation, pushing them to increase their investment in technological innovation and services, and to spend more resources on developing new technologies, upgrading the quality of their services and realizing the increase in the added value of their products. Therefore, government support can focus funds and resources on the realization of enterprise servitization strategy, thus accelerating the transformation of manufacturing industry from product-oriented to service-oriented.

Sixth, industry competition is significantly and positively correlated with manufacturing enterprise servitization at the level of 10%, and every 1 percentage point increase in industry competition brings about 1.7738 percentage point increase in the level of enterprise servitization, reflecting the strong pulling force of industry competition pressure on manufacturing servitization, and hypothesis H6 is verified. The main reason is that, first of all, in order to maintain competitive advantage in the fierce market competition, enterprises have to increase the investment in service innovation, constantly improve service quality and develop new service projects to meet the increasingly diversified customer needs, service innovation can not only enhance the market competitiveness of the enterprise itself, but also promote the overall service transformation process of the manufacturing industry, and promote the improvement of the level of servitization of the industry as a whole. On the other hand, the fierce competition in the industry makes the enterprises to be more competitive. On the other hand, the fierce competition in the industry so that enterprises are more sensitive to changes in market demand, enterprises in order to stand out in the highly competitive environment, pay more attention to from the customer's point of view, to provide personalized, customized services, through an understanding of customer needs, to achieve the differentiated service offerings to enhance customer stickiness and brand loyalty, and will also lead to the enterprise in the design and implementation of the service product It also encourages enterprises to improve and upgrade the design and implementation of service products to ensure that the service can respond to market changes in a timely manner to provide customers with sustained value.

The above model examines the impact of each conditional variable on the servitization of manufacturing industry in Shandong from the perspectives of technology, organization and environment, and the results show that factors such as digital foundation, technological innovation, organizational structure, human resources, government support and industry competition explain the performance of the servitization transformation of manufacturing enterprises, and the hypotheses H1, H2, H3, H4, H5, and H6 proposed in this research are all verified.

4.1.4 Conclusions on the analysis of influencing factors

This chapter explores the influence of digital infrastructure, organizational structure, human resources, government support and industry competition on the transformation of manufacturing servitization through the empirical analysis of the benchmark model. The findings show that the relationship between the factors is statistically significant and provides strong theoretical support and practical guidance for manufacturing servitization, based on the analysis of the findings:

(1) Digital infrastructure plays an important role in promoting manufacturing servitization. The optimization of digital infrastructure not only promotes data collection, storage and circulation, but also effectively reduces the cost of producers' access to user information and promotes the shift from producer-led to consumer-led manufacturing model. Through IoT technology, enterprises can obtain operational data during the product life cycle and provide value-added services for consumers, which in turn improves the overall level of servitization.

(2) Technological innovation has a role in promoting the servitization of the manufacturing industry. Among the six influencing factors, technological innovation can bring about the most obvious effect of servitization level enhancement, and a 1% increase in technological innovation can bring about as much as 34.9026 servitization level enhancement. From enhancing the added value of products, promoting the intelligence of production processes, realizing the deep integration of services and products, and promoting the transformation of service-oriented business models and the formation of ecosystems, technological innovation provides a powerful impetus for the transformation of the servitization of manufacturing enterprises. Under the current market environment, to achieve long-term sustainable development, manufacturing enterprises must make full use of the core driving force of

technological innovation, accelerate the pace of servitization, and enhance the competitiveness and market position of enterprises. Therefore, manufacturing enterprises should increase investment in technological innovation and deepen technological research and development to promote the smooth progress of their servitization.

(3) The optimization of organizational structure has a positive role in promoting the servitization of manufacturing industry. Streamlined hierarchical structure and flexible management mode can accelerate the information flow and decision-making efficiency, improve the enterprise's market response speed, and promote cross-sectoral collaboration, which provides a strong internal driving force for the manufacturing industry to servitization.

(4) The optimization of human resource structure also promotes the process of manufacturing service oriented. High-quality, complex talents not only enhance production efficiency, but also play an important role in service innovation and customer relationship management. By continuously strengthening staff training and incentive mechanism, enterprises can better adapt to changes in market demand, provide personalized services, and further accelerate the transformation of servitization.

(5) Government support has played an important role in reducing the cost of enterprise transformation and promoting technological innovation and R&D. The financial subsidies, tax incentives and innovation reward policies provided by the government have effectively promoted the investment of manufacturing enterprises in technological and service innovation and provided a strong policy guarantee for the servitization transformation of the manufacturing industry.

(6) Industry competition plays a key role in accelerating the process of manufacturing servitization. Under the fierce market competition environment, enterprises continuously increase their investment in service innovation to improve service quality and meet diversified customer needs, which promotes the servitization of enterprises. In addition, the competition in the industry has prompted enterprises to pay more attention to providing customized and personalized services from the perspective of customer needs, thus further promoting the improvement of the overall industry's servitization level.

In summary, the empirical research in this chapter shows that factors such as digital infrastructure, technological innovation, organizational structure, human resources, government support, and industry competition play a significant role in the servitization transformation of the manufacturing industry. By optimizing these key factors, firms can better cope with market challenges, accelerate the process of servitization, and enhance market competitiveness.

4.2 Research on the grouping path of servitization in manufacturing industry

4.2.1 Case selection, variable design and data calibration

Fuzzy-set Qualitative Comparative Analysis (fsQCA) is suitable for analyzing medium-sized case samples with 10 to 60 cases (Bennett & Elman, 2006; Y. Zhang et al., 2024). An excessively large or small sample size will lead to research complexity or lack of persuasiveness. Therefore, while ensuring that the case selection covers various types of manufacturing industries, this study adopts a random sampling method to select 60 manufacturing enterprises from the 102 samples in Shandong Province as research cases, including both industries with a high level of servitization and enterprises with a low level of servitization, thereby meeting the conditions for comparative analysis.

In addition, to alleviate the issue of limited diversity (i.e., the phenomenon where the number of observations is less than the number of conditional configurations), medium-sized case analyses usually set 4 to 7 antecedent conditions. Based on the TOE framework and the results of regression analysis, this study takes six key factors that significantly influence the servitization transformation of manufacturing—namely digital infrastructure, technological innovation, organizational structure, human resources, government support, and industry competition—as antecedent conditions. This is intended to explore the roles of core conditions and peripheral conditions in the servitization transformation paths of different enterprises, and to reveal the diverse paths driving the servitization transformation of manufacturing and their internal mechanisms.

Excel's PERCENTILE.INC function was used to calculate the 95th, 50th, and 5th percentiles for each variable, with minor adjustments made based on context. The calibration results for both the outcome and condition variables are shown in Table 4.5.

Table 4.5 Calibration anchors for variables

	Variable Name	Full Membership	Crossover Point	Full Non-Membership
Dependent variable	Servitization	13.0000	7.0000	4.0000
Condition Variables	Digital Infrastructure	310.0492	242.6963	225.7976
	Technological Innovation	0.0894	0.0459	0.0232
	Organizational Structure	0.9974	0.9529	0.7098
	Human Resources	59.6710	25.2450	3.4640
	Government Support	19.7851	16.8141	14.6558

Variable Name	Full Membership	Crossover Point	Full Non-Membership
Industry Competition	1.0000	0.9352	0.5182

4.2.2 Single-condition necessity analysis

(1) QCA Necessity Analysis

As shown in Table 4.6, the consistency levels of individual condition variables—whether for high levels of servitization or low levels—all fall below 0.9. Therefore, there is no need to conduct further coverage analysis. This finding indicates that manufacturing servitization is not dependent on any single condition; rather, it is a complex phenomenon driven by the joint effect of multiple factors.

Table 4.6 Necessity analysis results based on the QCA method

Varibles	Servitization		~ Servitization	
	Consistency	Coverage	Consistency	Coverage
DI	0.6010	0.5360	0.613104	0.684938
~DI	0.6468	0.5717	0.584689	0.647299
TI	0.5878	0.5374	0.613434	0.702526
~TI	0.6747	0.5822	0.59608	0.64426
FS	0.6636	0.5532	0.655397	0.684361
~FS	0.6214	0.5901	0.572101	0.680488
HR	0.6755	0.6307	0.535833	0.626604
~HR	0.6001	0.5079	0.684171	0.725326
GS	0.6324	0.5662	0.649732	0.728614
~GS	0.6969	0.6137	0.613134	0.676254
IC	0.6743	0.5569	0.641159	0.663225
~IC	0.5922	0.5685	0.571651	0.687354

Note: DI = Digital Infrastructure; TI = Technological Innovation; FS = Flat Structure; HR = Human Resources; GS = Government Support; IC = Industry Competition; "~" denotes the negation (absence) of the condition.

(2) NCA Necessity Condition Analysis

In this study, six variables were measured using the NCA package of the R software using two methods, Ceiling Regression - Free Disposal Hull (CR-FDH) and Ceiling Envelopment-Free Disposal Hull (CE-FDH), respectively. Since the ceiling line of CR-FDH is not suitable for accurately reflecting the distribution of data points, this research only reports the images obtained using the CE-FDH method, as shown in Figure 4.1 where the scatterplot demonstrates the degree of hindrance of each antecedent condition on the outcome variable, as expressed by the size of the blank area in the upper left corner of the ceiling line (Dul et al., 2020), where a blank upper left area indicates that lower levels of the antecedent variable fail to produce higher levels of the outcome,. As illustrated by V2-V1 in the figure it means that a low level of digital infrastructure is unable to produce a high level of servitization outcome.

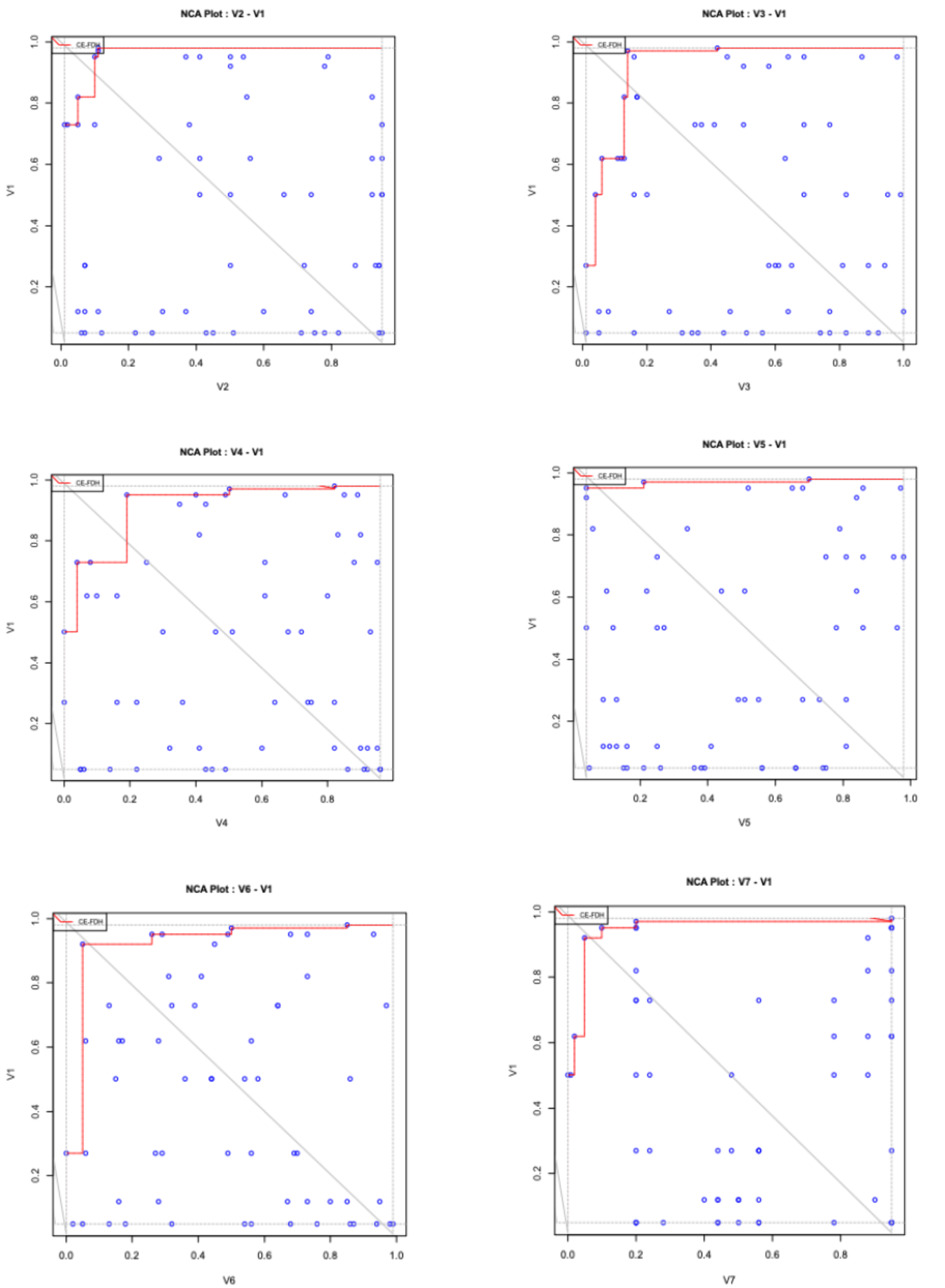

Figure 4.1 Scatter plots and ceiling lines

The necessity analysis results using two approaches—Ceiling Regression (CR) and Ceiling Envelopment (CE)—are shown in Table 4.7. The d value ranges from 0 to 1, where higher values indicate stronger effects: $d < 0.1$ indicates a small effect; $0.1 \leq d < 0.3$ indicates a medium effect; $0.3 \leq d < 0.5$ indicates a large effect; and $d \geq 0.5$ indicates a very large effect. The p-value tests the statistical significance of the effect size, and a threshold of $p < 0.05$ is commonly used. That is, if the necessity effect size of a condition is not less than 0.1 (Thiem, 2021), the *p*-value is less than 0.05, and the accuracy is above 95%, the condition can be considered a necessary condition for the occurrence of the outcome.

Table 4.7 Necessity analysis results using the NCA method

Condition	Method	Accuracy (%)	Ceiling Area	Range	Effect Size (d)	p-value
Digital Infrastructure	CR	96.7	0.013	0.87	0.015	0.774
	CE	100	0.018	0.87	0.021	0.695
Tech Innovation	CR	90	0.075	0.92	0.081	0.191
	CE	100	0.060	0.92	0.066	0.078
Flat Structure	CR	86.7	0.096	0.89	0.107	0.155
	CE	100	0.069	0.89	0.077	0.090
Human Resources	CR	98.3	0.007	0.87	0.009	0.682
	CE	100	0.010	0.87	0.011	0.667
Gov Support	CR	86.7	0.108	0.92	0.117	0.219
	CE	100	0.059	0.92	0.064	0.238
Industry Competition	CR	90	0.084	0.88	0.095	0.361
	CE	100	0.034	0.88	0.038	0.521

Note: Calibrated fuzzy set membership values.

Under the CR method, the d-value of flat structure was 0.107 with a p-value of 0.155, indicating a moderate effect size but lacking statistical significance. Using the CE method, the d-value was 0.077 with a p-value of 0.090, which also falls below the threshold for a moderate effect size and statistical significance, indicating that flat structure is not a necessary condition for the outcome. For government support, the CR method yielded a d-value of 0.117 with a p-value of 0.219, representing a moderate but non-significant effect size, while the CE method yielded a d-value of 0.064 and a p-value of 0.238, indicating a low effect size. This also suggests that "government support" is not a necessary condition for the outcome. As for the remaining variables, under both the CE and CR methods, the effect sizes of digital infrastructure, technological innovation, human resources, and industry competition were all below 0.1 and failed to reach statistical significance.

In conclusion, the NCA necessity analysis further demonstrates that none of the six conditional variables constitutes a necessary condition for the outcome. This implies that a single factor cannot solely determine the result, and the synergistic effect of multiple factors across the technological, organizational, and environmental dimensions is the key pathway to achieving the servitization transformation of the manufacturing industry.

The bottleneck level is the minimum level of attainment of the antecedent conditions (again expressed as a percentage) required to achieve a target outcome (measured as a percentage). As shown in Table 4.8, a minimum level of technological innovation of 6.4 per cent is required to achieve a 60 per cent level of MSS, in which case technological innovation constitutes a necessary condition for achieving the 60 per cent MSS outcome, while other factors are not necessary. To achieve a 90% manufacturing servitization level, at least 6.8% of the digital infrastructure level, 26.2% of the technological innovation level, 46.3% of the organizational structure level, 47.1% of the governmental support level, and 46.4% of the industry competition level need to be satisfied, implying that the digital infrastructure, technological innovation, organizational structure, governmental support, and industry competition constitute the 90% manufacturing servitization necessary conditions for the outcome. Similarly, for a 100% manufacturing servitization level, the six conditions of digital foundation, technological innovation, organizational structure, human resources, government support and industry competition are all necessary conditions for the outcome.

Table 4.8 Bottleneck levels (%) based on the NCA method

Servitization Level (%)	Digital Infrastructure	Technological Innovation	Flat Structure	Human Resources	Government Support	Industry Competition
0	NN	NN	NN	NN	NN	NN
10	NN	NN	NN	NN	NN	NN
20	NN	NN	NN	NN	NN	NN
30	NN	NN	NN	NN	NN	NN
40	NN	NN	NN	NN	NN	NN
50	NN	NN	NN	NN	NN	NN
60	NN	6.4	NN	NN	NN	NN
70	NN	13	3.6	NN	10.6	NN
80	2.9	19.6	24.9	NN	28.8	12.4
90	6.8	26.2	46.3	NN	47.1	46.4
100	10.8	32.7	67.6	65	65.3	80.4

Note: “NN” indicates “Not Necessary,” meaning the variable is not a bottleneck at that level of servitization.

4.2.3 Configuration analysis of conditional variables

The parameter settings for the group analysis refer to the existing studies and the size of the number of cases in this research, setting the case frequency threshold to 1, the raw consistency threshold to 0.8 (Rihoux & Ragin, 2009) and the PRI consistency threshold to 0.50 (Greckhamert et al., 2018).

4.2.3.1 Configuration analysis of high manufacturing servitization level

As shown in Table 4.9, there are six configuration paths (H1, H2, H3, H4, H5, H6) that lead to high levels of manufacturing servitization. The overall consistency is higher than 0.75, reaching 0.7956, indicating that across all sample cases, these six configurations consistently constitute sufficient conditions for high-level manufacturing servitization outcomes. The overall coverage is 0.4983, suggesting that these six configurations explain 49.83% of the high-servitization-level cases in the manufacturing sector.

Table 4.9 Configuration results for high-level manufacturing servitization

Conditional Varible	High-Level Manufacturing Servitization					
	H1	H2	H3	H4	H5	H6
Digital Infrastructure	⨂	⨂	⨂	⨂	●	•
Technological Innovation	⊗	⨂	⨂	•	•	⨂
Organizational Structure	●		•	⨂	⊗	⨂
Human Resources		●	●	●	●	●
Government Support	⨂	⊗		⊗	●	●
Industry Competition	•	●	●	⨂	⊗	•
Raw Coverage	0.3101	0.2726	0.2868	0.2189	0.2272	0.2132
Unique Coverage	0.0604	0.0071	0.0338	0.0263	0.0504	0.0086
Consistency	0.8411	0.8684	0.8189	0.8715	0.8582	0.8328
Solution Coverage	0.4983					
Solution Consistency	0.7956					

Note: ● indicates that the antecedent condition variable is present as a core condition; • indicates that the antecedent condition variable is present as a peripheral condition; ⨂ indicates that the antecedent condition variable is absent as a core condition; ⊗ indicates that the antecedent condition variable is absent as a peripheral condition; a blank cell indicates that the antecedent condition may or may not be present for the outcome to occur.

Configuration H1: Organizational Structure–Industry Competition Driven Type

(Low digital infrastructure × low technological innovation × high organizational structure × low government support × high industry competition).

This configuration is driven jointly by organizational structure as a core condition and industry competition pressure as an auxiliary condition. Meanwhile, digital infrastructure is missing as a core condition, technological innovation is missing as an auxiliary condition, and human resources may or may not be present. This indicates that even for enterprises lacking digital infrastructure and advanced technological resources, under intense industry competition, optimization of internal organizational structure can serve as a core driving force to achieve a high level of servitization. The consistency of this configuration is 0.8411, raw coverage is 0.3101, and unique coverage is 0.0604, suggesting that about 84.11% of enterprises satisfying this condition set demonstrate high levels of servitization, and the configuration explains 31.01% of the cases, with 6.04% uniquely explained by this path. Typical cases include Shandong Mining Machinery Group Co., Ltd. and Triangle Tire Co., Ltd.

Configuration H2: Human Resources–Industry Competition Driven Type

(Low digital infrastructure × low technological innovation × high human resources × low government support × high industry competition).

This configuration is jointly driven by high-level human resources and intense industry competition as core conditions. Digital infrastructure and technological innovation are missing as core conditions, and government support is absent. Organizational structure may or may not be present. This implies that in regions with limited technical foundations, high-quality personnel and competitive pressure can still drive high-quality servitization transformation. H2 shows a consistency of 0.8684, raw coverage of 0.2726, and unique coverage of 0.0071. That is, 86.84% of manufacturing firms satisfying this configuration exhibit high levels of servitization. This path explains 27.26% of cases, with 0.71% uniquely explained. A typical case is Sanwei Chemical. Shandong Sanwei Chemical Group Co., Ltd. is a high-tech enterprise focused on petrochemical, chemical, oil storage, and coal chemical industries, offering R&D, engineering services, catalysts, and chemical products. The main products or services are the production and sale of high-purity products such as n-propanal, n-propanol, isopropanol, gluteraldehyde, pentanol and other residual purification products such as mixed butanol, octanol and carbon XII; engineering design and general contracting business; and the production and sale of catalysts.

Configuration H3: Human Resources–Industry Competition–Organizational Structure Driven Type

(Low digital infrastructure × low technological innovation × high organizational structure × high human resources × high industry competition).

The path depends heavily on intense industry competition and human resources levels while organizational structure acts as supporting conditions. The necessary core conditions of digital infrastructure and technological innovation along with the peripheral need of government support are absent. Under competitive business pressure an organization can achieve elevated servitization levels by optimizing its personnel systems and operational infrastructure regardless of external policy supports. The consistency level of H3 measures 0.8189 and its raw coverage reaches 0.2868 alongside a unique coverage rate of 0.0338. The typical cases analyzed are Shantui Construction Machinery Co., Ltd. together with Shandong Xinhua Medical Instrument Co., Ltd. Located in the High-Tech Zone of Jining City, Shandong Province, Shantui's main business involves services that include technical consulting services, leasing services, and data and information system integration, in addition to basic sales as well as after-sales services such as product maintenance. Xinhua Medical's main business includes the production and sale of medical devices, design and construction of construction projects, manufacturing of special equipment, installation and renovation and repair, software development and sales, leasing services, machinery and equipment leasing, as well as technical and technological consulting and exchange services.

Configuration H4: Human Resources–Technological Innovation Driven Type

(Low digital infrastructure × high technological innovation × low organizational structure

× high human resources × low government support × low industry competition).

This grouping pattern takes high level human resources as the core condition and technological innovation as the auxiliary condition to drive the transformation of enterprise servitization, while digital foundation, organizational structure and industry competition are missing as the core condition and government support is missing as the marginal condition. It indicates that the lack of industry environment and organizational management structure can be effectively compensated by the strong drive of high-level human resource structure and technological innovation, to achieve a high level of servitization. The consistency of the H4 grouping pattern is 0.8715, the original coverage is 0.2189, and the unique coverage is 0.0263, which means that among all the enterprises that satisfy the H4 grouping pattern, 87.15% of the enterprises show high level of servitization, while the proportion of case samples that can be explained by this grouping is 21.89% and the proportion of samples that can be explained only by this grouping is 2.63%. The typical sample enterprise of this grouping is Yantai Longyuan Power Technology Co., Ltd, whose main business is energy saving business, environmental protection business and new energy business. The main products and services include fuel saving business, comprehensive energy saving renovation business, low-NOx combustion and industrial exhaust treatment, software and informationization, clean heating, photovoltaic, biomass, LNG, mixed ammonia combustion and other new energy field businesses.

Configuration H5: Technology–Human Resources–Government Support Driven Type

(High digital infrastructure × high technological innovation × low organizational structure × high human resources × high government support × low industry competition).

This grouping consists of high level of digital foundation, high level of human resources and high level of government support as the core conditions, and technological innovation capability as the auxiliary conditions to jointly drive the realization of enterprise servitization, while the organizational structure conditions and industry competition are missing as the marginal conditions, indicating that high level of technological conditions, high quality of human resources within the organization, and the support of the external government are able to better realize the transformation of the manufacturing industry into a servitization industry.H5 grouping condition The consistency is 0.8582, the original coverage is 0.2272, and the unique coverage is 0.0504, i.e., among all the sample enterprises that satisfy the condition situation of the H6 grouping, about 85.82% of the manufacturing enterprises show a high level of the degree of servitization transformation, and this grouping explains 22.72% of the sample enterprises, while the proportion of samples that can only be explained by this grouping is about 5.04%.H5 Typical samples of the grouping are Sekisen Electronics Corporation and New Wind

Optoelectronics Technology Corporation. The main business of Sekisen Electronics Co., Ltd. includes software development, production and system integration of power grid automation (including power grid dispatch automation and substation automation), power distribution automation and power plant automation equipment and systems, utility automation equipment and system products, and information security services. The company's main products include substation automation, grid dispatch automation, power distribution automation, utility automation, and measurement and evaluation services. The company has been awarded the honorary titles of “National High-tech Enterprise”, “Key High-tech Enterprise of the National Torch Plan” and “Postdoctoral Innovation Practice Base”. The company's product line in the field of power automation covers the power system generation, transmission, transformation, distribution, power, scheduling of each link, is one of the few manufacturers that can provide total solutions for power automation. The main business of New Wind Optoelectronics Technology Co., Ltd. is the research and development, production, sales and service of high-power power electronic energy-saving control technology and related products. The company's products include high-voltage dynamic reactive power compensation device, high school and low-voltage frequency converter, intelligent energy storage system device, rail transportation energy feedback device, coal mine explosion-proof, intelligent control equipment, which are widely used in new energy power generation, rail transportation, metallurgy, electric power, mining, chemical industry and other fields. The company has been honored as “Leading Brand in China Electrical Appliance Industry”, and the inverter has been honored as “Top 10 Brands in China High Voltage Inverter Market” and “National Key New Product” for many years, “China Famous Brand Products”. The company's “high-voltage elevator inverter project” was listed in the National Torch Plan Industrialization Demonstration Project by the Ministry of Science and Technology of the People's Republic of China, and the company's high-voltage inverter products have strong competitiveness in the domestic market.

Configuration H6: Environment–Human Resources–Digital Infrastructure Driven Type

(High digital infrastructure × low technological innovation × low organizational structure × high human resources × high government support × high industry competition).

This histogram has high level human resources and high-level government support as core conditions, digital infrastructure and industry competition as marginal conditions to assist in driving manufacturing servitization, while technological innovation and organizational structure are missing as core conditions. It indicates that with the support of digital infrastructure and the fierce competition in the industry, high quality human resources and government play a strong core driving role and can successfully achieve a higher level of manufacturing servitization transformation. The consistency of the H6 grouping is 0.8328, the original coverage is 0.2132, and the unique coverage is 0.0086, which indicates that 83.28% of all the sample enterprises that satisfy the grouping have firms exhibit a high level of servitization, 21.32% of the sample of cases explained by this grouping, and 0.86% of the cases uniquely explained by this grouping. The typical case enterprise of this grouping is Shandong Daon Polymer Material Co.

Finally, through the overall observation of the six conditional groupings of H1, H2, H3, H4, H5 and H6, it is found that in the six paths, human resources, as their prevalent core conditions, none of the groupings show a lack of human resource elements, thus it is not difficult to see that talent, as a dominant and promoter of the enterprise's servitization transformation strategy, plays a key role that cannot be ignored in the process of servitization transformation In this way, it is difficult to see that talent, as the leader and promoter of the enterprise servitization strategy, plays a key role in the servitization process that cannot be ignored.

4.2.3.2 Configuration analysis of low servitization levels in manufacturing

Using the "Truth Table Algorithm" function in fsQCA 4.1 software, this study also constructs a truth table to analyze the configurations leading to non-high levels of servitization in manufacturing. All possible combinations of conditions are listed in Table 4.10. There are four configuration paths for low-level manufacturing servitization outcomes (L1, L2, L3, L4), with an overall consistency exceeding 0.75, recorded at 0.8514. This indicates that these four configurations represent sufficient conditions for the stable occurrence of low servitization levels in the sample cases. The overall coverage is 0.5167, meaning that the four configurations can explain 51.67% of the cases exhibiting low levels of servitization in manufacturing enterprises.

Based on the specific conditions of each configuration, these can be categorized into two types:

Partial-factor presence type: including configurations L1 and L2

Single-factor presence type: including configurations L3 and L4.

Table 4.10 Low manufacturing service level grouping results

Condition Variables	Low-Level Manufacturing Servitization			
	L1	L2	L3	L4
Digital Infrastructure	⊗		●	●
Technological Innovation	●		⊗	⊗
Organizational Structure		●	⊗	⊗
Human Resources		⊗	⊗	⊗
Government Support	●	●	⊗	

Condition Variables	Low-Level Manufacturing Servitization			
	L1	L2	L3	L4
Industry Competition	⊗	⊗		⊗
Raw Coverage	0.2901	0.3494	0.2940	0.2158
Unique Coverage	0.0339	0.0548	0.0855	0.0006
Consistency	0.8980	0.8982	0.8713	0.8912
Solution Coverage	0.5167			
Solution Consistency	0.8514			

Note: ● indicates that the antecedent condition variable is present as a core condition; ● indicates that the antecedent condition variable is present as a peripheral condition; ⊗ indicates that the antecedent condition variable is absent as a core condition; ⊗ indicates that the antecedent condition variable is absent as a peripheral condition; a blank indicates that the antecedent condition variable may or may not be present for the outcome to occur.

(1) Partial-Factor Configuration Type

The partial-factor configuration type includes two configurations: L1 and L2. Their common characteristic in hindering the transformation towards servitization in manufacturing is the presence of only two factors, while other conditions are either missing or unspecified. Moreover, government support appears as a core condition, while industry competition is absent as a core condition.

Configuration L1: Digital Technology–Industry Competition Deficiency Type

(Low digital infrastructure × High technological innovation × High government support × Low industry competition).

The consistency of this grouping is 0.8980, the original coverage is 0.2901, and the unique coverage is 0.0339, indicating that 89.80% of all the samples that qualify for this grouping exhibit a low level of manufacturing servitization, with 29.01% of the samples explained by this grouping, and the only grouping that can be explained by it accounting for 3.39% of the sample. The L1 grouping is in the numerical base and industry The absence of competitive core conditions, even with strong technological innovation and high level of government support, still leads to low manufacturing servitization level, in which organizational factors may or may not exist. It indicates that in the process of manufacturing servitization, relying only on technological innovation and government promotion is not an effective strategy, technological innovation needs to be coupled with effective organizational structure and high-quality personnel, otherwise the driving force of technological innovation is difficult to be effectively transformed into real productivity. Typical sample enterprises of this pattern are Zhongtong Bus Co., Ltd, Zhongji Xuchuang Co., Ltd, Qingdao Han Cable Co. Among them, the main business of Zhongtong Bus is the manufacture and sale of buses; the main business of Zhongji Xuchuang is the manufacture and sale of motor stator winding manufacturing equipment and the manufacture of optical module equipment; the main business of Qingdao Han Cable is the research and development, production, sale and installation services of wire and cable and cable accessories; and the main business of Gore is the business of precision spare parts, the business of intelligent acoustic machine and the business of intelligent hardware.

Configuration L2: Human Resources–Industry Competition Deficiency Type

(High organizational structure × Low human resources × High government support × Low industry competition).

In the absence of human resources and competitive core conditions in the industry, it is still difficult to achieve a high level of servitization only through the optimization of organizational structure and government subsidies. Talent is the core and dominant of the organization's servitization transformation, in the absence of talent elements, the unilateral optimization of organizational structure is difficult to be effective, and the same government support needs to go to other elements to coordinate and cooperate to successfully promote the success of the servitization of the manufacturing industry. The consistency of this grouping is 0.8982, the original coverage is 0.3494, and the unique coverage is 0.0548, i.e., in all cases that satisfy this grouping, 89.82% of the enterprises show a low level of manufacturing servitization, and the samples of the cases that can be explained by this grouping are 34.94%, and the only samples that can be explained by this grouping are 5.48%, and the typical enterprises are Shandong Nanshan Aluminum Co. Nanshan Aluminum Company Limited, Aucma Company Limited and Shandong Weida Machinery Company Limited. Nanshan Aluminum's main business is the development, production, processing and sale of aluminum and aluminum alloy products and the production of electricity. Shandong Weida's main business is the development, production and sales of drill chucks, power tool switches, powder metallurgy parts, precision casting products, saw blades, machine tools and accessories, intelligent manufacturing system integration and intelligent equipment, mainly involved in the power tool industry, machine tool industry and intelligent manufacturing industry.

(2) Single-Factor Configuration Type

The single-factor configuration type includes configurations L3 and L4. Their common characteristic is that only digital infrastructure exists as a core condition, and human resources are absent as a core condition, leading to low levels of servitization due to the lack of multiple factors.

Configuration L3: Organization–Innovation–Government Support Deficiency Type

(High digital infrastructure × Low technological innovation × Low organizational structure × Low human resources × Low industry competition).

Digital infrastructure stands alone as the essential need for servitization performance, yet the entire set of conditions remains absent to produce low results. A servitization transformation requiring effectiveness requires combined efforts of digital infrastructure together with organizational and environmental factors as they operate independently of one another. This evaluation area shows that consistency stands at 0.8713 while raw coverage equals 0.2940 and unique coverage reaches 0.0855. The combination of this condition exists in 87.13% of cases which demonstrates 29.40% of total low servitization scores and 8.55% uniqueness. Shandong Hongyu Precision Machinery Co., Ltd. produces hydraulic lifters for tractors while Shandong New Grand Packaging Technology Co., Ltd. focuses on aseptic packaging R&D and combines those services with production and sales activities.

Configuration L4: Organization–Innovation–Government Support Deficiency Type

(High digital infrastructure × Low technological innovation × Low organizational structure × Low human resources × Low government support).

Unlike L3, the industry competition in this grouping state is shown as a missing condition, again only the core condition of digital base exists, while technological innovation, organizational structure and human resources are missing as the core conditions, which leads to a low level of servitization. The consistency of this grouping is 0.8912, the original coverage is 0.2158, and the unique coverage is 0.0006, i.e., among all the samples that satisfy this grouping, 89.12% of the enterprises will show low level of manufacturing servitization, and the proportion of the samples that can be explained by this grouping is 51.58%, and the only samples that can be explained by this grouping is 0.06%. The typical case of L4 is Hualming Power Equipment Co. Ltd, whose main business is the R&D, manufacturing and sales of CNC complete sets of processing equipment for steel structures; R&D, manufacturing, sales and services of transformer on-load tap-changers and non-excited tap-changers, as well as other power transmission and transformation equipment.

Through the overall analysis of the four low manufacturing servitization groupings of L1, L2, L3 and L4, it can be found that the absence of two conditions, human resources and industry competition, is a common core element leading to the low level of manufacturing servitization. That is, the lack of industry competition makes enterprises lack the motivation of servitization transformation, and vice versa shows that industry competition is the key driving force to promote the transformation of enterprise servitization, and industry competition provides the direction and thrust for the transformation of manufacturing industry, and under the fierce industry competition, the enterprises are in order to win the trust of the customers and seize the market share, so that they can carry out the transformation of servitization passively or actively to achieve the maximization of the interests of the enterprises. The lack of human resources is a key factor leading to the low level of servitization, which is in line with the conclusion of the overall analysis of the previous high-level servitization grouping, “Talent is the key element to promote the transformation of servitization” and further illustrates the role of enterprise human resources investment in the process of servitization.

4.2.4 Robustness test

In this study, the reliability of the study is verified by increasing the PRI consistency threshold from 0.5 to 0.6 and comparing the newly generated normalized analysis results with the original results, which reveals that there is a clear subset relationship between the conditional grouping and the original results, i.e., the results still remain robust after a higher PRI consistency threshold is set. In addition, this study further verified the reliability of the results by adjusting the original consistency from 0.8 to 0.85. After adjusting the original consistency to 0.85, the presented histogram results were still a subset of the original results, which once again proved the reliability and robustness of the study results.

4.3 Typological extension: Differentiated development models of enterprises under the interwoven TOE framework

Based on the results of fsQCA analysis, this study reveals six configuration paths of manufacturing servitization transformation under the TOE model framework. These configurations demonstrate the multiple pathways for the servitization transformation of manufacturing enterprises. However, although existing literature has conducted empirical analyses on different types of condition combinations, it has not yet distilled the universal patterns behind these pathways. Therefore, drawing on Professor Wang Shaoguang’s analytical model of policy learning—based on the two dimensions of “learning sources” and “learning promoters” (F. Wang et al., 2023; J. Wang & Li, 2024).

This study attempts to adopt a “classification + model” analytical framework to further explore the common characteristics of different development paths in enterprise servitization transformation.

4.3.1 Typological classification of different development models under the TOE framework

Through a combination of theoretical research and empirical analysis, this study finds that in the process of manufacturing servitization transformation, the elements of Technology, Organization, and Environment do not exist independently. Instead, they interact and intertwine, ultimately shaping differentiated outcomes in servitization transformation. Moreover, the roles of Technology, Organization, and Environment in the transformation process are not static. Different patterns of interaction among the three dimensions lead to variations in the outcomes of enterprise servitization. Therefore, based on the TOE theory, one of the core questions of this study is to analyze in depth the internal mechanisms of this interaction from a theoretical perspective. TOE theory, to a certain extent, addresses the interplay among Technology, Organization, and Environment and their interaction mechanism, thus providing theoretical support for understanding how they jointly influence manufacturing servitization.

Under the guidance of this theoretical framework, and based on the configuration results of fsQCA, this study further classifies the six high-level manufacturing servitization configurations into three development models through an interactional analysis from the three dimensions: Technology, Organization, and Environment. The models are the "Organization–Environment" Dual Synergy Model, the "Technology–Organization" Dual Synergy Model, and the "Technology–Organization–Environment" Triple Synergy Model, as shown in Figure 4.2. Among them, the "Organization–Environment" Dual Synergy Model includes configuration paths H1, H2, and H3; the "Technology–Organization" Dual Synergy Model corresponds to configuration H4; and the "Technology–Organization–Environment" Triple Synergy Model includes paths H5 and H6.

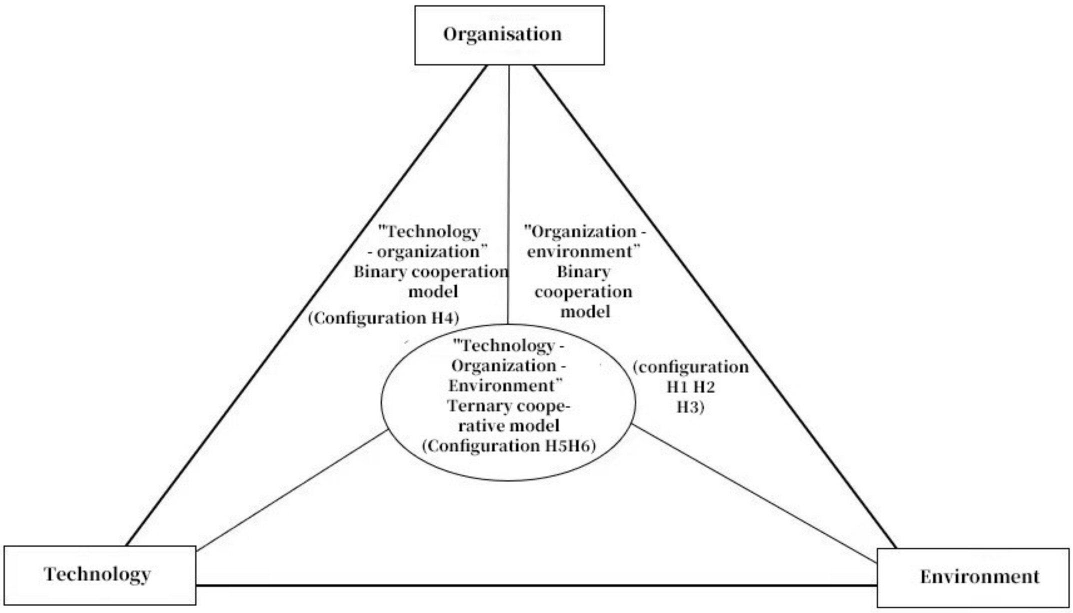

Figure 4.2 Differentiated paths of enterprise servitization transformation under the TOE framework

It should be noted that the process of manufacturing servitization transformation is driven by the synergistic effect of multiple factors, especially those within the three dimensions of

Technology, Organization, and Environment. This view serves as a foundational assumption of this study and has been thoroughly validated in the preceding sections. Based on this premise, this study integrates the distribution of technological, internal organizational, and external environmental conditions across the identified configurations, with a particular focus on the presence of core conditions, to further propose differentiated development modes for the six servitization transformation paths in manufacturing.

The classification of these development modes aims to highlight the relative influence of technological logic, organizational logic, and environmental logic in the transformation process of manufacturing servitization, rather than to suggest that any single dimension (e.g., technology or environment) acts independently. In other words, the three modes reflect the interwoven and interactive nature of technology, organization, and environment in shaping the servitization trajectory of enterprises.

Accordingly, the following case analyses will elaborate on the specific connotations of these development modes, further illustrating how different combinations of technology, organization, and environment contribute to the formation of manufacturing servitization.

4.3.2 Sample summary and analysis: Evidence from enterprises

Based on the typological scheme, three servitization patterns are identified—“organization–environment,” “organization–technology,” and “technology–organization–environment.” Drawing on the configurational conditions of each firm’s servitization, we inductively summarize the patterns among those enterprises that achieved a high level of servitization within the 102-case sample; the results are reported in Table 4.11. The subsequent analysis proceeds in two steps: (1) an overview of firms under each pattern, and (2) an in-depth description and diagnosis of the three developmental modes, using representative cases identified in the prior fsQCA configurational analysis.

Table 4.11 Summary of high-level service-oriented enterprise models

Organization-Environment Dual Synergy Model		Organizational-Technological Dual-Synergy Model		Technology-Organization-Environment Triple Synergy Model			
Enterprise Code	Abbrev.	Enterprise Code	Abbrev.	Enterprise Code	Abbrev.	Enterprise Code	Abbrev.
600955	WYGF	688309	HYHB	300569	TNZG	300285	GCCL
603536	HFGF	603187	HRLL	2768	GEGF	300343	LCJN
2481	STSP	603755	RCGF	688663	XFG	301069	KSXC
2270	FYSK	301022	HTK	600789	LKYY	300308	ZJZB
600336	AKM	688501	QDHB	2254	THXC	688557	LJZN
2286	BLB	300099	YLK	2838	DEGF	2111	WHGT
600760	ZHHB	300950	DGT	2241	GESX	2643	YTWR

Organization-Environment Dual Synergy Model		Organizational-Technological Dual-Synergy Model		Technology-Organization-Environment Triple Synergy Model			
600426	HLHS	301020	MFKJ	300699	GWFC	600309	WHHX
2526	SDKJ	300110	HRYY	688190	YLGF		
601163	SJLT	2655	GDDS	688035	DBKJ		
2469	SWGF	300105	LYJS	2339	JCDZ		
680	STGF			300848	MRXC		
600587	XHYL			603639	HLE		

Regarding data sources, to minimize potential “introspective” bias during interviews, this study relies primarily on officially disclosed information from publicly listed companies as the key evidentiary basis. Public disclosures have the advantage of having undergone broad social scrutiny, which enhances the authenticity and reliability of their content and, in turn, supports the objectivity and credibility of the findings. Moreover, the use of public materials provides a more comprehensive and diverse set of perspectives, thereby strengthening the persuasiveness of the analysis.

4.3.2.1 "Organizational–environmental" dual synergy model

Weiyuan Co., Ltd., Huifa Co., Ltd., Shuangta Food Co., Ltd., Fain CNC Co., Ltd., Aokema Co., Ltd., Baolingbao Co., Ltd., AVIC Black Panther Co., Ltd., Hualu Hengsheng Co., Ltd., Shandong Mining Machinery Co., Ltd., Triangle Tire Co., Ltd., 3D Engineering Co., Ltd., Shantui Co., Ltd., and Xinhua Medical Co., Ltd. have all undergone service transformation through the “organization-environment” dual-coordination model, with an average service level of 0.741. While relatively weak in the technological dimension (digital infrastructure and technological innovation), these companies successfully mitigated this shortcoming by combining internal optimization with external leverage. Under this model, enterprises primarily prepare for service transformation through internal organizational restructuring and human resource integration/enhancement. They heavily rely on and effectively utilize government support (e.g., policy subsidies, demonstration projects) and industry competitive pressures (e.g., avoiding homogeneous price wars through service differentiation) to drive transformation. Ultimately, this model yields significant service-oriented outcomes, demonstrating that even without leading technological innovation, successful transformation is achievable through “soft power” and external support. Commonly seen in traditional manufacturing enterprises, their service orientation typically focuses on extending services based on existing products (such as after-sales support, maintenance, turnkey integration, and contracting) rather than highly digitalized innovative services.

Specifically, Shandong Mining Machinery Group Co., Ltd. achieved its service-oriented transformation through a dual-coordination model of “organization-environment” within a complex “technologically lagging-organizationally efficient-highly competitive” environment. A comprehensive assessment of its service volume and depth indicates a service-oriented level of 8. Technologically, Weifang—Shandong Mining Machinery's regional base—lags behind other cities in digital economic development. While the company possesses a certain production technology foundation, its investment in technological innovation during digital transformation has not significantly surpassed industry averages. Its R&D expenditure ranks near the bottom among sample enterprises. The company's continued reliance on traditional production processes and technologies imposes certain constraints on advancing its service-oriented transformation. However, in the organizational dimension, Shandong Mining Machinery demonstrates relatively advanced management practices. It has adopted a flatter organizational structure, enhancing organizational flexibility and adaptability, which provides strong support for rapid transformation. Regarding the environmental dimension, the “Special-purpose Equipment Manufacturing” sector where Shandong Mining Machinery operates is characterized by exceptionally fierce competition. Based on the Herfindahl-Hirschman Index (HHI), the industry's competitive intensity ranks first among the sample enterprises. This places Shandong Mining Machinery under immense pressure in terms of pricing and technological innovation, compelling it to increase investment in service innovation to maintain its competitive edge in the market. Simultaneously, despite government policies supporting manufacturing upgrades and transformation, Shandong Mining Machinery ranks relatively low in government subsidies received. Consequently, the company must rely more heavily on its own capabilities to achieve breakthroughs during its transformation. Despite facing dual challenges of technological limitations and insufficient government support, the company successfully transitioned from traditional manufacturing to a service-oriented model within the fiercely competitive industry, leveraging its superior organizational structure and flexible management approach. Leveraging the flexibility and efficiency of its flat organizational structure, Shandong Mining Machinery rapidly adapts to external market changes, driving service model innovation. Despite limitations in technological innovation capabilities, the company has progressively enhanced the intelligence and value-added nature of its services through collaborations with external technology partners. This has gradually established a competitive edge in value-added services centered on equipment management and maintenance. In summary, Shandong Mining Machinery has driven its service-oriented transformation by leveraging organizational strengths and external competitive pressures. Despite limitations in technology and government support, the synergistic effects of organizational structure and environmental conditions have enabled the company to achieve a high-level service transformation.

Compared to Shandong Mining Machinery, Shandong Sanwei Chemical Group Co., Ltd. also exhibits relative lags in technological innovation and digital transformation. However, its organizational strength is underpinned by a high-quality human resource structure and a workforce with advanced educational backgrounds. Despite limited government support, Sanwei Chemical has achieved a relatively high level of service transformation—rated at 9—driven by intense industry competition and leveraging its superior engineering technical service capabilities and organizational resource advantages.

Shandong Xinhua Medical Equipment Co., Ltd. adheres to a “customer-first” service philosophy, establishing a “360° comprehensive brand service” model encompassing maintenance, spare parts supply, and feedback mechanisms. This service model extends beyond traditional after-sales support to cover the entire product lifecycle, fully embodying a customer-centric corporate culture and values. With a service level of 13, it ranks among the top manufacturing enterprises in Shandong Province. Xinhua Medical still has room for improvement in technological investment and innovation-driven development. Although technological updates and R&D capabilities are crucial for competitiveness in the highly competitive medical device industry, Xinhua Medical has secured its market position through robust organizational capabilities and a high-caliber human resource structure. The company employs 32.57% of personnel with bachelor's degrees or higher, has recruited three national-level talents and leading experts, and possesses numerous highly skilled professionals. Its technical staff and management team demonstrate outstanding expertise, strong adaptability, and deep industry knowledge. Additionally, its implementation of a relatively flat management structure enables more flexible decision-making and faster response times, helping the company maintain agility in intense market competition. From an environmental perspective, in 2023, the “Special Equipment Manufacturing” sector where Xinhua Medical operates ranked first in industry competitiveness intensity. Regarding government support, although Xinhua Medical, as a member of the national strategic emerging industries, received only moderate-to-low government backing (ranking 31st), government support still played a certain role in driving its service transformation process. Overall, Xinhua Medical achieved a high-level service transformation through its efficient organizational structure, high-quality human resources, and flexible market responsiveness amid intense industry competition.

These sample enterprises operating under the “organization-environment” dual-coordination model demonstrate that during service transformation, even when technically disadvantaged, sound organizational strategies and sensitivity to environmental changes can equally drive successful transformation. When significant technological advancement is unattainable in the short term, enterprises can achieve service-oriented transformation through organizational optimization and environmental support within the “organization-environment” model. However, it is noteworthy that while this model demonstrates pronounced effectiveness in the early and mid-stages of transformation, the long-term absence of technological capabilities may become a bottleneck for further enhancing service depth (such as developing high-end intelligent services) and efficiency.

4.3.2.2 "Organizational–environmental" dual synergy model

Hengyu Environmental Protection, Hairong Cold Chain, Richen Co., Ltd., Haitai Technology, Qingda Environmental Protection, Yuloka, Degute, Sealing Technology, Huaren Pharmaceutical, Gongda Electronics, and Longyuan Technology all underwent service transformation through the “organization-technology” dual-coordination model, with an average service transformation score of 0.613. A defining characteristic of this model is the absence or insufficiency of environmental factors (government support and industry competition). Enterprises primarily rely on their own capabilities—specifically, internal synergy between technology and organization—to drive service transformation. These companies possess technological innovation capabilities or a digital foundation, enabling them to develop technical platforms or intelligent products that support serviceization. Concurrently, their organizational structures and human resources adapt to service-oriented operations, ensuring technologies are effectively deployed and converted into service capabilities.

For instance, Yantai Longyuan Power Technology Co., Ltd. achieved over 50% service revenue in 2023, with a service transformation index of 9, indicating a high level of service orientation. Technologically, Yantai Longyuan consistently prioritizes independent innovation, possessing relatively strong R&D capabilities. Its “Ultra-Low NOx Emission Technology for Deep-Tuning Conditions in CFB Boilers Based on Flue Gas Recirculation” project received the Third Prize in China's Power Science and Technology Awards. The “Research and Application of Intelligent Combustion Technology for Anti-Coking and Efficiency Enhancement in 350MW Supercritical Counterflow Boilers” project was appraised by the Chinese Society for Electrical Engineering as reaching internationally leading standards. Furthermore, Yantai Longyuan Power emphasizes integrating technological innovation with service delivery, continuously achieving technological breakthroughs that elevate overall service quality and standards while enhancing customer satisfaction. Organizational Dimension: In human resources, Yantai

Longyuan Power boasts a high proportion of employees holding bachelor's degrees or higher (69.64%), demonstrating significant advantages in talent recruitment and development. During its service transformation, the technical capabilities and professional backgrounds of its highly educated workforce enable the company to develop more precise and efficient service solutions, thereby meeting the diverse needs of different customer groups. Environmental Dimension: The company ranks 40th and 45th among sample enterprises in terms of government support and industry competitiveness, respectively. Operating in a relatively less competitive sector with limited government backing, the company faces constrained access to resources such as policy subsidies and tax incentives. This may impact on its investment in technological R&D and service innovation. Therefore, analyzing the three dimensions of technology, organization, and environment, Yantai Longyuan Electric Power's service transformation relies on its technological innovation advantages and high-quality human resource structure. Despite relatively weak external environmental support, the company has achieved certain breakthroughs in the service domain by continuously enhancing technological innovation and R&D investment, realizing a relatively high level of service transformation. Its distinctive path driven by the dual forces of technology and organization provides a reference model for enterprises with relatively unfavorable external environments to successfully achieve service transformation.

Additionally, the average service-oriented level of sample enterprises operating under the “organization-technology” dual-synergy model was relatively low among the three categories, underscoring the critical importance of external environmental support. Without strong external drivers (such as policy) or pressures (like competition), while technological innovation can provide powerful momentum for service-oriented transformation, relying solely on internal R&D makes the transition more challenging and potentially slower. and the process may be slower. However, once successful, such enterprises may exhibit strong market adaptability and independence. The lack of environmental support, however, means they face greater challenges in securing resources and gaining market recognition.

4.3.2.3 "Technology-organizational–environmental" triad synergy model

Tianneng Heavy Industry, Guoneng Co., Ltd., Xinfengguang, Lukang Pharmaceutical, Taihe New Materials, Daon Co., Ltd., Goertek, Guangwei Composite Materials, Yunlu Co., Ltd., Debang Technology, Merui New Materials, Hailier, Guoci Materials, Lianchuang Energy Saving, Kaisheng New Materials, Zhongji Equipment, Lanjian Intelligent, Weihai Guangtai, Yantai Wanrun, Wanhua Chemical, and Jicheng Electronics achieved service transformation through a tripartite synergy model of "technology-organization-environment," with an average service level of 0.8101. These enterprises did not rely on a single advantage but made effective investments and developments across the three dimensions of technology, organization, and environment, forming powerful synergies. This represents the most ideal and comprehensive transformation model. In the technological dimension, they possess robust digital infrastructure and technological innovation capabilities, providing a solid foundation for service-oriented initiatives such as intelligent services, remote product monitoring, and predictive maintenance. At the organizational level, they have restructured internal frameworks and optimized human resources, establishing agile organizations, teams, and talent systems capable of supporting service operations. The environmental dimension actively leverages government policy support or adeptly responds to industry competition, transforming external pressures into drivers for transformation. Such enterprises are often industry leaders or innovators, and their service transformation typically represents a systematic upgrade encompassing "products + services + solutions."

For instance, Jicheng Electronics Co., Ltd. has a service-oriented assessment score of 13. Its core business encompasses software development, production, system integration, and information security services for automation equipment and systems in power grids, distribution networks, utilities, and power plants. Within the energy and power digitalization sector, the company's product portfolio spans all segments of the power system, positioning it as one of China's few manufacturers capable of delivering comprehensive smart grid automation solutions. Technologically, the city where Jicheng Electronics is located possesses relatively well-developed digital infrastructure, enabling the company to fully leverage digital technologies to enhance its operational capabilities and product innovation. In its smart grid and power automation solutions, Jicheng Electronics employs advanced digital technologies for data acquisition, processing, and analysis, delivering more efficient and intelligent services. Its sustained independent innovation serves as a key driver for service-oriented transformation. The company not only maintains a leading position in power automation and smart grid sectors but also continuously increases R&D investment, with an R&D expenditure ratio of 7.39% in 2023. Its robust technological innovation capabilities have elevated the intelligence and automation levels of its products in new energy solutions and smart city construction, providing strong support for its service-oriented transformation. Through independently developed high-reliability main and auxiliary protection devices for substations and power grid dispatch systems, it has successfully transformed traditional power equipment into intelligent, service-oriented products, further advancing its shift from equipment manufacturing to intelligent service provision. Organizational Dimension: Jicheng Electronics maintains a well-structured workforce of technical talent and management personnel, with a high proportion of highly educated employees. Notably, those holding bachelor's degrees or higher account for 65.42% of the workforce, ranking second among Shandong manufacturing enterprises. The company's R&D team possesses strong technological innovation capabilities, providing ample technical reserves and talent support for its service-oriented transformation. Environmental Dimension: Government support for Jicheng Electronics is also a crucial factor in its service-oriented transformation path. In 2023, government subsidies accounted for 17.80% of Jicheng Electronics' revenue. The company has also participated in multiple national-level projects and industry standard development. Recent policy support in fields like new energy and smart grids has provided robust external backing for its growth. Its development trajectory highlights the government's pivotal role in driving enterprise service transformation while demonstrating the positive impact of policy support on technological innovation and industrial upgrading. In summary, Jicheng Electronics' service-oriented transformation path demonstrates robust technological innovation capabilities, a sound human resource structure, and strong government policy backing. It represents a typical pathway to achieving high-level service transformation through the synergistic interaction of technology, organization, and environment.

Finally, the average servitization level (0.8101) achieved by enterprises under the “technology-organization-environment” triadic synergy model significantly exceeds that of the other two models. This indicates that triadic synergy most effectively propels enterprises toward extending into high-value-added service segments. Servitization transformations under this model are typically more profound, stable, and resilient to risks, possessing strong potential for long-term development. Therefore, while enterprises cannot achieve balanced development across all three dimensions in the short term, they should leverage their strengths and characteristics to adopt either the “organizational-environmental” or “organizational-technological” dual-coordination model as their initial servitization strategy. Concurrently, they must begin laying the groundwork for long-term strategic needs, striving to transition toward the “technological-organizational-environmental” triadic coordination model.

4.4 Chapter summary

Through a research method combining qualitative comparative analysis (fsQCA) and necessity condition analysis (NCA), this chapter aims to deeply analyze the path of local manufacturing servitization and reveal the multiple driving mechanisms behind it. First, the fsQCA method helps to identify the mechanisms of different conditional variables by dealing with the interactions of complex causal relationships. Specifically, fsQCA captures the interaction effects of multiple factors involved in the process of manufacturing service transformation, and by considering each case as a combination of a set of conditional variables, it is able to analyze how these conditions jointly contribute to the transformation outcome, thus avoiding the errors associated with single-variable analysis and comprehensively revealing multiple causality affecting manufacturing service transformation. Unlike fsQCA, the NCA method complements the limitations of fsQCA in necessity analysis by quantitatively assessing the degree of necessity of each condition and is able to quantitatively analyze the intensity of the impact of conditions on the outcome, thus providing a more precise explanation for understanding the causal mechanism of manufacturing servitization transformation. The combination of these two methods can comprehensively improve the reliability and precision of the study. fsQCA provides a qualitative perspective on the interactions of the condition variables, while NCA provides a nuanced explanation of the degree of necessity of each condition through quantitative analysis, and the combination of the two greatly enhances the understanding of the path of servitization transformation of the manufacturing industry in this study.

Through the fsQCA research method, this study first conducts necessity analysis on six key condition variables, focusing on assessing whether these conditions are necessary for manufacturing servitization transformation. The core of the necessity analysis is to test whether each condition variable is significantly correlated with the emergence of the outcome variable (i.e., servitization transformation) through the level of consistency. If a condition is consistently present in the emergence of an outcome, it can be regarded as necessary for that outcome to occur. Through the analysis of consistency and coverage metrics, this research finds that while different conditions play a role in the emergence of servitization transformation in some cases, these conditions are not independent enough to determine the outcome of servitization transformation on their own. Therefore, this chapter tentatively concludes that a single factor is not sufficient to explain the complex phenomenon of manufacturing servitization, and that the synergy of multiple factors is the key to the success of the transformation. To further refine the understanding of the necessity of conditions, this chapter quantifies the degree of necessity of each condition for servitization transformation through NCA. In the results of NCA, none of the six conditions of digital infrastructure, technological innovation, organizational structure, human resources, governmental support, and industry competition similarly constitutes a necessary condition for servitization transformation, and these conditions, although they have a certain impact on the transformation of manufacturing servitization, do not meet the These conditions have some influence on the servitization of the manufacturing industry, but they do not reach the standard of necessary conditions. Therefore, it can be speculated that the servitization of manufacturing industry is not the result of a single condition, but the product of the interaction of multiple conditions.

Conditional grouping analysis is the core content of this chapter, which reveals the different combinations and synergistic groupings of the six conditions of digital foundation, technological innovation, organizational structure, human resources, government support and industry competition through the function of “truth table algorithm” of the fsQCA method, and further indicates that the servitization is not a single path but is based on the internal resources of different enterprises and the external environment, and that the servitization is not the result of a single condition. It further shows that servitization is not a single path, but a multiple path chosen according to the internal resources and external environmental conditions of different enterprises. Finally, we get six grouping paths to realize high-level servitization, and name H1 to H6 as organizational structure-industry competition-driven, human resources-industry competition-driven, human resources-industry competition-organizational structure-driven, human resources-technology innovation-driven, technology-human resources-government support-driven, and environment-human resources-digital foundation-driven according to the emergence of their condition variables. The six paths are then categorized based on the typology. Building on the typological classification, the six configurational pathways were mapped onto the TOE framework, yielding three servitization transition modes: the “organization–environment” dyadic coordination mode, the “technology–organization” dyadic coordination mode, and the “technology–organization–environment” triadic coordination mode. On this basis, we inductively summarize patterns among high-servitization enterprises in the sample, and conduct (i) an overall analysis of firms’ servitization characteristics under each mode and (ii) pathway analyses of representative cases. This allows for an in-depth examination of the realization mechanisms and outcomes associated with different modes, thereby offering practicable references for manufacturing firms operating under similar configurational conditions. The results of the mode-specific analyses indicate that, among the three servitization modes, the “technology–organization–environment” triadic coordination mode achieves the most favorable performance. Servitization transitions under this mode are more stable, exhibit stronger resilience to risk, and demonstrate greater potential for sustained long-term development.

This chapter combines the fsQCA and NCA methods to analyze the path of servitization of manufacturing industry in Shandong from multiple perspectives, revealing its multiple driving mechanisms and transformation paths. By analyzing the necessity and sufficiency of different conditions, the study shows that the success of manufacturing servitization transformation does not rely on a single factor, but the synergy of multiple conditions. Whether it is technological innovation, government support, or industry competition and other factors, the interaction between them jointly shapes the outcome of the transformation. The findings of this research provide theoretical guidance for the servitization of local manufacturing industries and empirical evidence for the formulation of related policies. Future research can be further extended to other regions or industries to verify the universality of the findings of this study and to explore the deeper impact of different combinations of conditions on servitization transformation.

Chapter 5: Suggestions for Manufacturing Servitization Transformation and Future Outlook

Servitization in manufacturing industry continues as an essential and permanent trend which shapes industrial development. All manufacturing enterprises require promoting servitization and strengthening service capabilities at both the industry and individual enterprise levels. The research applies the TOE model and theoretical evaluation together with empirical data to investigate the complex servitization mechanisms and finds various paths companies can follow during their evolution. The chapter provides concrete guidance to government agencies and enterprise organizations for facilitating the successful servitization development of manufacturing companies.

5.1 Government level

The government takes part as the top-level economic controller to guide manufacturing servitization transformation. Servitization represents an essential business strategy which transforms operations to propel economic development along with national market status. Rising competitive pressures affect manufacturing operations because of increasing global economic connectivity and accelerating technological progress. Organizations need to boost their production effectiveness while strengthening their service abilities and developing new service patterns to maintain long-term development. The research demonstrates that official direction and budget distribution remain essential activators for servitization processes. Well-constructed government policies assist companies in removing their technological barriers while activating high-quality servicing improvements.

5.1.1 Strengthen financial support and precisely drive servitization

The manufacturing servitization process receives major performance influence from government backing that functions as the primary motivational factor in certain transformation paths. The successful execution of high-level servitization demands both financial support together with resource management under policy direction. Manufacturing enterprises need governments to enhance their financial support for servitization transformation through strong backing systems with safety measures. For servitization and service innovation to succeed both technological capabilities and skilled personnel alongside sufficient monetary funding become essential. All servitization needs stable funding because it supports attracting talent acquisitions and conducting R&D programs. The government needs to function as a financial resource distributor by investing capital into servitization to enable businesses to handle funding demands for continuous development.

The transformational efforts will receive financial backing from governments through designated funding programs and tax reduction programs and monetary support strategies. A strict system to monitor fund distribution and specific selections regarding recipients forms the backbone for successful implementation to optimize policy results. Resources need to move directly to the most essential areas of servitization implementation. Strong innovative capabilities and high potential represent two main factors that justify priority selection for funding among small and medium-sized enterprises. The lack of sufficient capital resources becomes a key obstacle for these firms to advance their operations. Because of governmental backing businesses can obtain amplified advantages. Support that targets specific businesses enhances both finance relief and market innovation and transformation in competitive environments.

5.1.2 Foster a technological innovation environment to drive servitization

Technological innovation is one of the most powerful driving factors influencing the service-oriented manufacturing industry. It not only requires enterprises to innovate as R&D entities, but the government should also create an environment and atmosphere that is conducive to enterprise innovation, so that the results of technological innovation can be transformed into service-oriented power and effectively promote the realization of the overall service-oriented industry. On the one hand, it is necessary to strengthen the construction of digital infrastructure. Digital technology has become the core force in promoting the transformation of manufacturing industry into a service-oriented industry. To achieve the integration of artificial intelligence, big data, cloud computing, the Internet of Things and other technologies with service-oriented industries and win new development opportunities for the manufacturing industry, the construction of digital infrastructure must keep up. The government should increase investment in digital infrastructure construction, promote the popularization and application of digital technology, to help enterprises realize intelligent and customized service provision infrastructure guarantees in the service process, and promote the deep integration of digital technology and manufacturing services. On the other hand, the government should also encourage and support technological innovation, create a regional innovation atmosphere, and further promote the integration of industry, academia and research.

The servitization of the manufacturing industry not only relies on the improvement of traditional production technology but also requires the innovation of new technologies and service models. The government should focus on supporting the technological research and development of manufacturing enterprises in intelligent manufacturing, service innovation, help enterprises break through the bottleneck of traditional technology, and develop new service products that meet market demand. By providing research and development funds, technical support, it helps enterprises to carry out technological innovation, encourages enterprises to carry out research and development and innovation of service products, and promotes technological progress in the entire industry. It also deepens the cooperation between industry, academia and research, encourages the cooperation between manufacturing enterprises and universities and scientific research institutions, promotes the transformation and application of technological innovation results, and further enhances the overall innovation capabilities of enterprises.

5.1.3 Improve talent policies to sustain servitization

All servitization transformation pathways depend on talent, particularly for technical workers and service-management employees. The development of talent through enterprises alone is insufficient because government-market synergy ensures long-term sustainability of skilled personnel.

The acquisition of talent should be supported by governments who need to optimize recruitment strategies while implementing active recruitment methods for servitization personnel. Higher material and non-material benefits combine to lure qualified professionals into manufacturing servitization positions.

The government needs to establish alliances between enterprises and universities to create multispecialist professionals who match servitization requirements. Such initiatives fill talent shortages and create solutions to protect the relationship between academic education and industrial needs that produce skilled professional talent streams.

5.1.4 Strengthen market regulation to ensure healthy competition

Industry competition has provided a strong driving force in the process of manufacturing service transformation, enabling enterprises to actively implement service strategies to win a place in the competition. As the process of manufacturing service transformation progresses, industry competition has become more intense, and the market environment has become more complex. A good market environment is the basis for continuous innovation and transformation of enterprises. The government should strengthen supervision of the industry, ensure the stability of market order and fair competition, crack down on unfair competition, and ensure that enterprises can continue to innovate and progress in fair market competition, to play a positive role in the development of the manufacturing industry. At the same time, the government should also promote information sharing and cooperation through the establishment of platforms such as industry associations, help enterprises better understand changes in industry trends and market demand, and thus provide a more stable and healthy market environment for the transformation of manufacturing service transformation, and promote enterprises to make correct strategic decisions in the process of service transformation.

The role of the government in the transformation of manufacturing industry into service is multifaceted, involving policy support, technological innovation, talent introduction, industry supervision and other fields. It is necessary not only to help enterprises resolve the service dilemma through financial support, but also to promote technological innovation and continuous upgrading of service models by building a good innovation ecosystem, laying the foundation for the long-term sustainable development of the manufacturing industry. The introduction and training of talents is also one of the points of the government in the process of service. Only the coordination and cooperation between enterprises and the government can retain the talents needed for the service of manufacturing industry in the long term. In addition, maintaining a good market competition environment is also an important responsibility of the government in the process of service. In summary, the government should provide all-round support and guarantee for the transformation of manufacturing enterprises into service enterprises through a series of measures such as increasing policy support, promoting technological innovation, strengthening talent training and introduction, and improving market supervision.

5.2 Enterprise-level recommendations

Whether an enterprise can successfully achieve servitization depends on whether it can promote technological innovation, organizational structure adjustment, human resource optimization and other adaptations to the service-oriented strategic process through innovative and flexible strategic adjustments. With the increasingly fierce market competition, manufacturing enterprises must adjust their management model, technical system and business structure to maintain their competitive advantage. They must not only focus on improving efficiency on the production side, but also on improving service capabilities to gain a foothold in long-term market competition. Therefore, the servitization of manufacturing enterprises is not only a simple business transformation, but also a comprehensive adjustment of the entire enterprise structure, culture and strategy.

(1) Increase investment in technological innovation

Technological innovation is one of the core driving forces for the transformation of manufacturing industry into service industry. In the process of manufacturing industry transformation, technological innovation is not limited to the upgrading of products and production processes, but also requires comprehensive innovation in service models, management models and business processes. With the rapid development of information technology, especially in the fields of big data, cloud computing, artificial intelligence, technological innovation can effectively promote the in-depth development of manufacturing industry and service industry. Enterprises should increase their investment in research and development of new technologies, especially in intelligent manufacturing, digital services and automation technologies. Through technological innovation, enterprises can improve production efficiency, reduce operating costs, and improve service quality and customer experience.

Manufacturing enterprises can increase the added value of services and expand their business scope by developing new service products or service models. For example, enterprises can launch intelligent products in combination with Internet of Things technology, establish intelligent customer relationship management systems, provide customers with personalized customized services, and improve service quality. In addition, enterprises should also pay attention to the breadth and depth of technology application, integrate advanced technical means into the entire production and service system, improve operational efficiency through intelligent management, and provide more flexible and customized services.

Technological innovation should also focus on cross-industry and cross-field integration and promote the combination of traditional manufacturing industry with modern information technology and Internet technology. For example, enterprises can develop cloud platforms or mobile Internet applications to establish real-time interactive channels between enterprises and customers, further improving service response speed and customer satisfaction. Through technological innovation, manufacturing enterprises can gain competitive advantages in the fierce market competition, while also creating more service value and promoting the continuous advancement of the service-oriented process.

(2) Optimize organizational structures and management models

In the process of servitization of manufacturing industry, it is crucial to optimize the organizational structure and management model. Enterprises should adjust the existing organizational structure according to their own service needs, implement flat management, reduce management levels, and improve decision-making efficiency. The traditional pyramid management model may restrict the flexibility and response speed of enterprises in the process of servitization. Therefore, enterprises should make decisions more efficient and flexible by streamlining management levels and shortening the information transmission chain.

Optimizing the organizational structure is not only about simplifying the management level, but also about building a cross-departmental and cross-functional collaboration mechanism. In the process of servitization, enterprises need to break the traditional production management model, enhance communication and collaboration between different functional departments, and form a more flexible and efficient service team. For example, sales, customer service, R&D and production departments should work closely together to promote servitization and ensure the smooth delivery of service products and customer satisfaction. At the same time, enterprises should pay attention to the shaping of employee culture, especially the cultivation of service awareness and innovative spirit. Enterprises can enhance employees' service awareness, innovation ability and teamwork spirit through employee training, team building and cultural shaping. In the process of servitization, employees are the core force of transformation, and their participation and enthusiasm directly affect the success or failure of transformation. Therefore, enterprises should stimulate employees' innovative motivation through cultural construction and training and provide strong internal motivation for servitization. In addition, enterprises should also focus on the training of senior management teams. Servitization is not only a change in technology and management, but also a transformation of strategic thinking. The senior management team of an enterprise needs to fully realize the significance and value of servitization, formulate a clear transformation strategy, and lead all employees to achieve this goal. The senior management team needs to have a forward-looking strategic vision, be able to grasp industry trends and market changes, and provide direction for the enterprise's servitization.

(3) Emphasize talent development and recruitment

In the process of servitization, the role of human resources cannot be ignored. The servitization of enterprises not only depends on changes in technology and management but also relies on high-quality human resources support. Enterprises need to cultivate and introduce high-quality talents with interdisciplinary capabilities according to the needs of servitization. In addition to traditional manufacturing technical talents, enterprises also need talents with professional skills in multiple fields such as service management, customer relations, and information technology. Especially in today's rapid development of information technology, enterprises need many talents with technologies such as data analysis, cloud computing, and big data management. These talents can help enterprises better realize digital transformation and improve service capabilities. To this end, enterprises should increase investment in human resources, especially in the introduction and training of professional and technical talents in the service field. Enterprises can cooperate with universities and scientific research institutions to carry out talent training and introduction plans to provide enterprises with a steady stream of high-quality talents. In addition, enterprises can also help existing employees improve their service capabilities and technical levels by establishing internal training mechanisms to ensure the sustainable development of the talent team.

Enterprises should also encourage employees to conduct cross-departmental and cross-industry learning and practice to enhance their comprehensive capabilities. In the process of servitization, enterprises need to have the ability to collaborate across functions, and employees need to flow between different business areas to accumulate cross-domain knowledge and experience. By establishing a cross-departmental cooperation platform, companies can promote knowledge sharing and experience exchange among employees, thereby promoting the improvement of overall innovation capabilities.

(4) Advance digital transformation and smart manufacturing

Digital transformation is a part of the transformation of manufacturing industry into servitization. With the rapid development of information technology, especially the application of technologies such as big data, cloud computing, and artificial intelligence, digital transformation has become a key means for manufacturing industry to achieve servitization. Enterprises should actively promote digital transformation and use advanced digital technologies to improve production efficiency and service quality. Through the construction of digital platforms, enterprises can achieve information sharing, resource integration, and improve the accuracy and flexibility of services. Intelligent manufacturing is one of the contents of digital transformation, which can help enterprises realize the intelligence of production processes, improve production efficiency, and reduce costs. Intelligent manufacturing enables enterprises to produce flexibly according to customer needs and improves the ability to provide personalized customized services through the integration of automation, informatization, and digitalization. Enterprises can improve the production efficiency and quality of products by introducing advanced production equipment and technologies and enhance service capabilities through the application of intelligent technologies. For example, enterprises can use artificial intelligence technology to optimize production processes, reduce manual intervention, and improve the flexibility and efficiency of production lines. In addition, digital transformation can promote interaction and cooperation between manufacturing enterprises and customers and enhance customer experience. Enterprises can achieve real-time interaction with customers by building digital platforms, adjust products and services in a timely manner according to customer feedback, and improve customer satisfaction. Digital transformation can not only improve the operational efficiency of enterprises but also enhance their market competitiveness and promote the sustainable development of the servitization process.

(5) Strengthen external collaboration and environmental awareness

In the process of servitization, enterprises cannot rely solely on their own strength but also need to interact and cooperate closely with the external environment. The external environment includes multiple factors such as government policies, industry competition, and market demand, which have a profound impact on the transformation process of enterprises. Enterprises should actively interact with the external environment and use government policy support and industry competition pressure to promote the smooth progress of servitization.

Firstly, government policies play a vital role in the servitization of enterprises. The government can help enterprises achieve servitization by issuing support policies, providing financial support, and encouraging technological innovation. Enterprises should pay close attention to changes in government policies and adjust their strategies in a timely manner in order to seize policy dividends and increase the possibility of successful transformation.

Secondly, industry competition is also an external driving force for the servitization of enterprises. In a highly competitive market environment, if enterprises do not carry out servitization in a timely manner, it will be difficult to maintain competitiveness. By analyzing industry trends and competitive situations, enterprises can formulate reasonable transformation strategies and gain a leading advantage in servitization.

In addition, enterprises can also obtain external resource support and enhance service innovation capabilities through cooperation with industries and scientific research institutions. Through cooperation, enterprises can introduce external technology, knowledge and market resources to enhance their own innovation capabilities and market adaptability.

(6) Implement diversified development strategies

With the constant changes in market demand, enterprises need to diversify, break through the traditional manufacturing model and expand into the service sector. The diversification strategy helps enterprises to add new sources of income based on the original manufacturing business, diversify risks, and enhance the market adaptability and competitiveness of enterprises. Through diversification, enterprises can not only enhance their core competitiveness but also meet the changing market demand and promote sustainable development. Enterprises can develop new service products, provide value-added services, and carry out after-sales services according to changes in market demand. By providing diversified services, enterprises can attract more customers and expand their market share. In addition, enterprises can implement customized services according to the needs of different regions and markets to enhance customer satisfaction and loyalty.

The servitization of the manufacturing industry is a complex systematic project involving technological innovation, organizational restructuring, human resource management, digital transformation and other aspects. Enterprises in the transformation process need to comprehensively consider the changes in the internal and external environment and continuously improve their service capabilities and core competitiveness through technological innovation, organizational adjustment, and the introduction of talents. In the fierce market competition, only through continuous innovation can enterprises stand out in the transformation and realize sustainable development.

5.4 Contributions

The study advances scholarship on manufacturing servitization by proposing and empirically validating a comprehensive analytical framework that integrates the Technology–Organization–Environment (TOE) perspective with the resource-based view, dynamic capabilities theory, and resource-dependence theory. This integrative lens captures how technological assets and routines, organizational structures and human capital, and environmental forces—particularly policy instruments and competitive pressures—jointly shape firms' progression from product-centric to service-intensive business models. Methodologically, the combination of regression analysis and fuzzy-set qualitative comparative analysis (fsQCA) allows the inquiry to reconcile net-effect estimation with configurational causality, thereby illuminating not only whether individual factors matter but also how distinct bundles of conditions cohere into viable pathways toward servitization.

Empirically, drawing on the year of 2023 dataset of 60 manufacturers in Shandong Province, the analysis uncovers six configurational routes that can be meaningfully synthesized into three mode archetypes aligned with TOE: the organization–environment dyadic mode, the technology–organization dyadic mode, and the technology–organization–environment triadic mode. The typological induction clarifies the characteristic features, enabling conditions, and likely bottlenecks of each mode. The findings indicate that the triadic mode tends to generate the most stable and resilient servitization outcomes, as firms orchestrate technological innovation, organizational adaptation, and environmental alignment in a mutually reinforcing manner. The dyadic modes, although capable of producing high servitization levels under specific circumstances, are more vulnerable to constraints—whether stemming from technological deficits, organizational misalignment, or insufficient external impetus—underscoring the value of multi-facet coordination.

The inquiry further contributes by elucidating the mechanism of multi-factor interaction across technology, organization, and environment. Technological capabilities—ranging from digital infrastructure to innovation capacity—emerge as the principal engine that drives the deepening of service content and the intelligence of service delivery. Organizational elements—structure, governance routines, incentive systems, and human capital—constitute the enabling architecture that translates technological potential into repeatable, scalable service offerings. Environmental elements—policy support, regulatory signals, and competitive intensity—provide both resources and directional guidance, shaping firms' opportunity sets and risk perceptions. By tracing how these elements combine to form high-servitization configurations, the study moves beyond linear accounts and offers a richer account of heterogeneity in pathways and outcomes.

A further theoretical payoff lies in extending the scope and applicability of the TOE model to the context of servitization in manufacturing. The integrated framework demonstrates that TOE is not merely a checklist of antecedents but a scaffold for theorizing complementarities and trade-offs among capabilities, structures, and environmental conditions. In particular, the typology clarifies boundary conditions under which specific dyadic arrangements can stand in for a temporarily missing third pillar, and it specifies the circumstances in which a shift toward triadic coordination becomes necessary to sustain growth, enhance risk resilience, and unlock longer-term performance gains. In this way, the study furnishes a more granular vocabulary for designing and sequencing servitization interventions.

The analysis also carries implications for measurement and research design. By pairing econometric estimation with fsQCA, the study illustrates the value of plural methodological strategies for capturing both average effects and equifinal configurations. The reliance on officially disclosed information improves replicability and mitigates introspective bias, while the calibration choices in fsQCA and the operationalization of key constructs provide a baseline for subsequent work to refine variable selection, strengthen construct validity, and standardize data processing. Such refinements will enhance the explanatory power of the model and facilitate comparisons across organizational types, technological regimes, and industry contexts.

Looking ahead, several avenues merit systematic exploration. Expanding the set of technological, organizational, and environmental conditions will deepen the model’s coverage of antecedents, for example, by incorporating ecosystem participation, platform complementarity, data governance, and inter-firm collaboration architectures. Longitudinal designs and quasi-experimental strategies could more clearly identify causal effects and capture dynamic capability building as firms iterate through servitization stages. Beyond treating servitization as an outcome, future work should also examine servitization capability as a strategic antecedent that shapes innovation productivity, customer experience, brand equity, and competitive positioning in global markets; this shift of perspective would connect servitization to broader performance portfolios and industry competitiveness.

Generalizability likewise calls for extending sampling frames to encompass small and medium-sized enterprises, industry leaders, and multinationals across sectors with differing capital intensity and regulatory exposure. Comparative analyses across ownership forms and supply-chain positions would clarify how governance structures and bargaining power mediate the returns to servitization. International comparisons—spanning economies with distinct industrial structures, policy regimes, and technological endowments—would help isolate institutional moderators and reveal where TOE-based mechanisms are portable versus context-dependent. Applying the integrated TOE framework across such settings would stress-test its robustness and sharpen its scope conditions.

In sum, by articulating an integrative TOE-anchored framework, uncovering configurational pathways and an empirically grounded typology of modes, and demonstrating how technological, organizational, and environmental elements interact to propel or hinder transformation, the study enriches the theoretical depth of servitization research and closes an empirical gap on multi-factor interaction. At the same time, it sketches a research agenda that prioritizes stronger measurement, more diverse samples, rigorous causal identification, and cross-national comparison. Taken together, these contributions furnish scholars with a more nuanced theoretical apparatus for analyzing servitization and equip managers and policymakers with actionable guidance for designing context-sensitive, resilient, and scalable servitization strategies in manufacturing.

5.5 Chapter summary

This chapter gives extensive recommendations of the manufacturing servitization transformation and provides the directions towards the future research based on the theoretical and empirical findings achieved in the course of the study. In the government policy, the combination of sources of financial support and the increase in financial support by using the instruments of selective funding and tax incentives, technological innovation ecosystem support through digital infrastructure investment and cooperation between the industry, academia, and research, and the talent development policy to nurture projects in cross-disciplinary fields, and improved market regulation to achieve fair competition and information exchange can be involved.

The recommendations at the enterprise level include investing more in the technological innovation process to integrate digital technologies, organizational structure optimization, executed using flat management and cross-functional processes, prioritizing the recruitment and training of talents in interdisciplinary skills, further digital transformation and smart manufacturing to achieve personalized services, enhancing outside cooperation to use policy incentives and market understanding, and diversified strategy of development to expand service content coverage.

Chapter 6: Conclusions

Based on the research framework, the previous chapters have completed the theoretical analysis, model construction, and empirical investigation. This chapter focuses on reviewing the overall research process and outcomes and further refines and interprets the results in depth.

First, drawing on the practice of servitization transformation among manufacturing enterprises in Shandong Province, this study highlights the necessity of servitization in the context of global competition. It also reveals the contradiction in China’s manufacturing sector being large but not strong. On this basis, the study focuses on the complex causal mechanisms of manufacturing servitization, attempting to analyze and explain from an academic perspective the underlying logic and synergistic driving mechanisms.

Second, to lay the foundation for empirical research on manufacturing servitization, this study systematically reviews and describes existing theoretical achievements and practical developments from both theoretical and practical perspectives, providing a solid background for subsequent analysis.

Third, after establishing theoretical groundwork and factual overview, and following the general principles of theoretical model building, the study uses the TOE framework, referencing classic theories such as the Resource-Based View, Dynamic Capabilities Theory, and Resource Dependence Theory, to elaborate on the foundational role of technology, organization, and environment in servitization transformation. On this basis, the study identifies six key conditions: digital infrastructure and technological innovation under the “technology” dimension; organizational structure and human resources under the “organization” dimension; and government support and industry competition under the “environment” dimension.

Fourth, under the TOE framework, the study examines the complex causal mechanisms of enterprise servitization transformation from the interactive logic of technology, organization, and environment.

Lastly, based on the TOE model, the study takes 208 manufacturing enterprises in Shandong Province as the research sample and uses data from 2023. By integrating OLS regression, fsQCA, and case study methods, it conducts single-factor impact analysis, conditional configuration analysis, and representative case analysis to reveal the complex causal mechanisms and configuration characteristics of manufacturing servitization.

This study reveals the technological, organizational, and environmental factors in driving manufacturing servitization transformation through a multifactor analysis of manufacturing servitization transformation in Shandong Province. As pointed out in the studies of Vendrell et al. (2017) and Huxtable and Schaefer (2016) technological innovation, especially the development of digital technology, plays a crucial role in the advancement of manufacturing servitization. The empirical analysis in this research further verifies that technological innovation is the most important factor driving the transformation of manufacturing servitization, and the results of the study show that the construction of digital infrastructure and technological innovation provides a strong transformation driving force for manufacturing enterprises. The empirical findings on the impact of internal organizational elements and external environmental factors on manufacturing servitization similarly validate the points made by various scholars in the existing literature. Therefore, based on existing literature, this study empirically examines the influence of the corresponding elements of technology, organization and environment dimensions on manufacturing servitization through the data of manufacturing enterprises, which enriches the empirical support of the views of scholars on the influencing factors of manufacturing servitization. On the basis of the empirical analysis of the influencing factors, this study analyzes the service transformation paths of different enterprises through fsQCA method, and identifies six different service transformation paths, and unlike the previous studies, through analysis of these paths based on the multiple interactions of technological, organizational, and environmental conditions, this study concludes that the service transformation of the manufacturing industry is affected by the synergistic effect of multiple factors of technology, organization, and environment, and finds that the service transformation of the manufacturing industry is influenced by the three dimensions of the technology, organization, and environment. At the same time, it is found that among the three dimensions, the organizational element is the most central and indispensable key element, especially human resources play a fundamental role in the process of servitization.

Therefore, synthesizing the research results, this research makes up for the lack of existing literature on the role of different elements in the servitization process, and concludes that in the process of manufacturing servitization, the technology element can provide a strong impetus to drive the realization of the transformation of servitization, while the organization element plays a fundamental role and an indispensable role in the process of servitization, and the external environment plays a key role in the process of servitization through the guidance of resources and direction. The external environment plays a key role in the servitization process through the guidance of resources and direction.

In summary, this study not only verifies some conclusions in the existing literature, but also, through differentiated research methods and local cases, comprehensively considers the interaction of technology, organization and environment, and innovatively proposes the roles and influences of each element in the path of servitization transformation under the framework of TOE, which further reveals the multifarious paths of servitization transformation of the manufacturing industry as well as the core points therein. The specific research conclusions will be presented in the following.

6.1 Conclusion 1: Influencing factors of servitization transformation in manufacturing

Based on the TOE (Technology-Organization-Environment) model and combining with the existing literature, this research proposes six research hypotheses and constructs a corresponding benchmark model, and conducts a regression analysis on enterprise data for the 2023, to empirically test and profoundly answer research questions regarding the impact of the three dimensions of technology, organization, and environment on the servitization transformation of manufacturing enterprises. The empirical analysis shows that the six independent variables of technology, organization and environment dimensions, digital base, technological innovation, organizational structure, human resources, government support and industry competition factors, all have a positive impact on manufacturing servitization, which is in line with Vendrell et al. (2017) and X. Zhao et al. (2022).

Xiao (2021), Xiao et al. (2014) and Tong and Zhang (2021) are consistent with the findings of other studies. The results of the study provide strong support for enterprises in promoting the process of servitization, and the hypotheses proposed in this research are verified, among which technological innovation has the greatest impact on the servitization of the manufacturing industry. Therefore, based on the results of the empirical analysis, we can conclude that “digital foundation, technological innovation, organizational structure, human resources, government support and industry competition factors play a significant role in promoting manufacturing servitization”, this research concludes that manufacturing servitization is the result of multiple factors in the technological, organizational and environmental dimensions, which is in line with the findings of Y. Li et al. (2022) and Luo and Liu (2024) that manufacturing servitization is the result of the multiple factors in the technological, organizational and environmental dimensions. that the transformation of manufacturing servitization is the result of the interaction of multiple factors, the difference is that this research further deepens the multi-factor study of manufacturing servitization from the dimensions of technology, organization and environment. In addition, this study quantifies the necessity of conditions through the NCA method, further complementing Santamaría et al. (2012) and Y. Gao et al. (2024) who mainly emphasize technological adequacy at the expense of necessity, and expanding the theoretical explanation.

From the technological dimension, the conditions of digital infrastructure and the technological innovation capability of enterprises have been shown to be the foundational conditions and key elements that drive the servitization of manufacturing enterprises. The construction of digital infrastructure provides enterprises with efficient integration and optimization of information flow, data flow and material flow, enabling manufacturing enterprises to achieve smarter and more accurate decision-making support in the process of operation, and thus enhancing their ability of servitization. The level of digital economic development in the region where the enterprise is located has a profound impact on the technological innovation and servitization of the enterprise. In regions where the digital economy is developing rapidly, enterprises can make use of abundant digital resources and technology platforms to quickly realize the implementation of their servitization strategy. In addition, enterprises' investment and achievements in technological innovation also play a role in servitization transformation. Technological innovation does not only refer to the upgrading of products and production processes; it also includes the innovation of service models. For example, by developing new service products and building new customer relationship management systems and information systems, enterprises can enhance their service capabilities and improve service quality, further promoting the process of servitization. The regression analysis of this research shows that technological innovation has the greatest impact on the servitization of manufacturing industry, especially in the context of digital economy, the leapfrog upgrade of technology has an important role in promoting the transformation and upgrading of enterprises. Technological innovation is not only the basic driving force of manufacturing servitization, but also a key factor for enterprises to maintain their competitive advantages. Only through technological innovation can manufacturing enterprises gain momentum for sustainable development in the fierce market competition.

The driving role of elements within the organization on the transformation of servitization should not be ignored. The management mode and human resource conditions of enterprises play a central role in the process of servitization. In particular, the adjustment of the enterprise's organizational structure can effectively enhance flexibility and responsiveness within the enterprise, so as to better adapt to market changes. In terms of organizational structure, many manufacturing enterprises implement flat management and reduce management levels for more efficient decision-making and execution when undergoing servitization. In addition, the shaping of culture within the organization is also a considerable factor in promoting servitization. An open and innovative organizational culture can motivate employees to actively engage in service innovation and service quality improvement, thus forming a strong endogenous momentum. In terms of human resources, the cultivation and introduction of skilled personnel is crucial to the implementation of an enterprise's servitization strategy. The servitization of the manufacturing industry requires not only professionals with production technology, but also talents with multifaceted skills in service management, customer relations and information technology. These talents are not only the leaders and practitioners of the servitization strategy, but also the key to innovation and optimization of the service model. Therefore, enterprises must invest more in human resources in the process of servitization, especially in the cultivation and introduction of professional and technical talents in the service field.

In terms of the external environment, government policies and industry competition play an unnoticeable external driving character in the servitization of manufacturing enterprises. Government policies, especially supportive policies for digital transformation and servitization transformation of manufacturing enterprises, play a role in promoting financial support, technical guidance and market development of enterprises in the process of servitization. For example, the government encourages enterprises to carry out technological R&D and innovation and promotes the smooth progress of their servitization transformation by means of tax exemptions, financial subsidies and project support. On the other hand, industry competition has likewise had a far-reaching impact on the servitization of enterprises. With the increasingly fierce competition in the market, enterprises must face the increasing pressure of survival. Especially in some highly competitive industries, enterprises are often unable to stand out in the competition without significant servitization. As a result, the exogenous pressure from industry competition forces firms to seek breakthroughs in servitization transformation in addition to traditional manufacturing operations to maintain or expand their market share. The results of the empirical analysis show that government support and industry competition factors in the external environment play a significant role in promoting the servitization of the manufacturing industry, especially in the context of digital transformation, where the government's policy support and the pressure brought by industry competition jointly promote the acceleration of the servitization process of manufacturing enterprises.

6.2 Conclusion 2: Conditional configurations of manufacturing servitization

Based on the "TOE" model, this research combines the qualitative comparative analysis (QCA) method to explore the characteristics of manufacturing servitization and its core influencing factors. The study adopts the data of manufacturing enterprises in Shandong in 2023, and includes six condition variables that have passed the significance test in the analysis, focusing on the grouping effect of manufacturing servitization, including the necessity of individual conditions and the grouping paths of the conditions, as well as the key role of the core conditions in the servitization of the manufacturing industry, compared with the findings of the single paths of the studies of H. Zhou et al. (2025), N. Zhou and Bao (2021, 2022), this study reveals a more complex configurational mechanism and provides empirical support for understanding the multiple realizations of manufacturing servitization, answering the research question regarding through which paths manufacturing enterprises in Shandong Province successfully implement servitization transformation. The findings are as follows:

(1) None of the six condition variables—digital infrastructure, technological innovation, organizational structure, human resources, government support, and industry competition—individually constitute a necessary condition for manufacturing servitization. Among them, human resources show the highest explanatory power, further confirming their central role in manufacturing servitization.

(2) The development pathways of manufacturing servitization exhibit a diversified trend, indicating that improvement is not achieved through a single model. The study identifies six distinct high-servitization configurations:

Configuration H1: Low digital infrastructure * Low technological innovation * High organizational structure * Low government support * High industry competition

Configuration H2: Low digital infrastructure * Low technological innovation * High human resources * Low government support * High industry competition

Configuration H3: Low digital infrastructure * Low technological innovation * High organizational structure * High human resources * High industry competition

Configuration H4: Low digital infrastructure * High technological innovation * Low organizational structure * High human resources * Low government support * Low industry competition

Configuration H5: High digital infrastructure * High technological innovation * Low organizational structure * High human resources * High government support * Low industry competition

Configuration H6: High digital infrastructure * Low technological innovation * Low organizational structure * High human resources * High government support * High industry competition

Despite differences in their specific compositions, all six configurations lead to high levels of servitization, demonstrating a “multiple paths to the same goal” pattern.

(3) Among the six high-servitization configurations, all six conditions—digital infrastructure, technological innovation, organizational structure, human resources, government support, and industry competition—appear as core conditions in different configurations, indicating their roles in promoting manufacturing servitization. Notably, human resources appear as a core condition in five configurations and are not absent in the remaining one, reaffirming their fundamental and universal importance in the servitization process. Industry competition appears in four configurations, suggesting that external competitive pressure is a key driving force for high-level servitization, consistent with previous research (Zuo & Liu, 2024).

Additionally, digital infrastructure, technological innovation, organizational structure, and government support each appear as core conditions in two configurations, indicating that these variables remain important drivers of manufacturing servitization under different contexts.

6.3 Conclusion 3: Development modes and logical mechanisms of manufacturing servitization

Under the TOE framework, and based on the interaction among manufacturing enterprises’ technological, organizational, and environmental dimensions, this study constructs a typological triangle to analyze differentiated development modes of servitization transformation in manufacturing, profoundly answering the research question regarding the path characteristics and core factors of the successful implementation of manufacturing servitization transformation in Shandong Province. Based on this framework, fsQCA analysis reveals six distinct servitization transformation paths. These paths demonstrate how enterprises adopt different strategies under various technological, organizational, and environmental conditions and are categorized into three development modes: the "organizational–environmental" dual synergy mode, the "technological–organizational" dual synergy mode, and the "technological–organizational–environmental" tri-synergy mode.

Specifically, in the "technological–organizational–environmental" tri-synergy mode, technology, organization, and environment jointly interact and reinforce each other to drive servitization transformation. When these three elements collaborate, manufacturing firms can better leverage technological advantages, optimize internal structures, and adapt to external changes to achieve servitization. In this mode, technological advancement offers support, organizational restructuring enables efficiency, and external environmental demands compel innovation and adaptation. Therefore, servitization transformation under this model is the most comprehensive, sustainable, and effective.

When one key element is lacking, the influence of other elements is amplified. In the "organizational–environmental" dual synergy mode, even in the absence of advanced technologies, organizational and environmental logics can still drive transformation. For instance, under external market shifts, firms proactively adjust service models and reallocate internal resources to enable transformation. In such scenarios, organizational adaptability and environmental influence are decisive. Thus, despite lacking technological advantages, firms can still achieve servitization through strong organizational management and environmental drivers.

Furthermore, in the "technological–organizational" dual synergy mode, technology and organization jointly promote servitization transformation when external environmental impact is limited. Internal drivers such as technological innovation and organizational reform play a greater role. Technological logic provides the foundation for innovation, while organizational logic ensures smooth implementation. In this mode, even without strong external pressures, firms can still successfully transform through ongoing technological advancement and organizational efficiency.

Analysis of the three servitization transformation modes shows that organizational factors consistently play a vital role in all models. Regardless of the specific mode, the organization is the primary agent of transformation. The success of servitization is inseparable from organizational support. Be it the tri-synergy or dual synergy modes, organization remains the driving force. Internal structures, resource allocation, and human resource management are essential in the transformation process. Hence, organization serves as a core component in all development modes.

It is noteworthy that a "technological–environmental" dual synergy mode without organizational factors does not exist. Servitization transformation is not solely driven by technological innovation or external environmental changes. It must be implemented through internal organizational structures, resource coordination, and management mechanisms. Technology and environment provide momentum and direction, but execution must rely on internal coordination.

Moreover, the roles of technology, organization, and environment in servitization are dynamically evolving. At different stages, the influence of each element shifts. As the economic and social environment changes, adjustments in technology, internal structure, and external conditions affect the transformation path. In particular, with globalization and digitalization, external changes are becoming more complex. Thus, enterprises must increasingly emphasize environmental factors during transformation. Simultaneously, technology development and organizational adjustments must respond to external dynamics. Consequently, manufacturing servitization is a dynamic process that continuously evolves and optimizes with changing internal and external conditions.

6.4 Research limitations and outlook

6.4.1 Research limitations

Based on the practical context of the servitization transformation of Shandong's manufacturing industry, this paper selects the TOE framework as the theoretical perspective and combines the classic resource - based theory, dynamic capability theory, and resource dependence theory to construct a force model encompassing three dimensions: technology, organization, and environment. This model is used to explain the complex causal mechanism of manufacturing servitization. However, there is still significant room for improvement in the construction of the theoretical model, the universality of sample selection, and empirical testing.

First, in the construction of the theoretical model, this paper emphasizes that the servitization transformation of the manufacturing industry is influenced by the mutual dependence and interaction of multiple factors, which is a basic assumption based on the Marxist view of universal connection. However, considering the specific context and importance of the research, this paper only selects representative technological, organizational, and environmental conditions and fails to consider more relevant factors such as organizational systems, organizational cultures, and business environments. This may affect the comprehensiveness and explanatory power of the model. Secondly, although this paper considers the influence of each conditional variable in the technology, organization, and environment dimensions on the outcome variable and the configurational relationship among these conditions, in-depth analysis of the mutual influence among these conditions is still insufficient. For example, how technological conditions affect the role of organizational elements and the mutual influence among various conditions within the model still need further exploration.

Secondly, the geographical concentration of sample selection limits the external validity of the research conclusions to a certain extent. The empirical data in this paper mainly rely on listed manufacturing companies in Shandong Province. Although Shandong, as a major manufacturing province with a complete range of industrial categories in China, is highly representative, its industrial structure shows distinct "heavy - industry" characteristics. Resource - intensive and capital - intensive industries such as traditional heavy chemicals, energy, and machinery manufacturing account for a relatively high proportion in the sample. This specific regional industrial characteristic may lead to the context - dependence of the research conclusions. Specifically, this study finds that the "organization - environment" model plays a core role in the servitization transformation path of Shandong enterprises, which is closely related to the high transformation cost of heavy - asset industries and their strong dependence on external resources. However, if the scope is extended to the Yangtze River Delta or Pearl River Delta regions, different conclusion scenarios may be obtained. These regions are dominated by technology - intensive and light - asset industries such as electronic information, biomedicine, and precision manufacturing. In this context, the driving logic of servitization transformation may no longer highly depend on external policy support but be more controlled by the agile iteration ability in the "technological innovation" dimension and the support of digital facilities. In other words, in the scenario of light manufacturing with a higher degree of digitalization and a more perfect market mechanism, some technological absence configurations identified in this study may no longer be applicable and may be replaced by differentiated paths driven by high - tech innovation. Therefore, the configurational path obtained in this study based on the Shandong context may have specific "heavy - industry dependence", and potential heterogeneous differences need to be fully considered when extending the conclusions to emerging industries or regions with significantly different industrial attributes.

Finally, there is still room for improvement in the design of empirical research. In terms of variable operation, although the measurement standards and methods of the conditional variables in this paper have been repeatedly applied and verified by scholars, the proxy variables constituting the conditional variables may not fully and accurately represent the content required by the hypothesis. In the process of variable assignment and calibration, due to the interference of subjective factors, there may be certain irrationalities, which need to be further verified in subsequent research.

In addition, although this paper proposes the concept of "service breadth" from the perspective of the "product aspect" involved in services and incorporates it into the "servitization level" framework, thereby enriching the connotation of the "servitization level", the measurement method based on the "business scope" data of listed companies mainly shows the static characteristics of the servitization of manufacturing enterprises and cannot effectively reveal and analyze the dynamic evolution process of the servitization level of enterprises. Therefore, future research can further adopt the dynamic QCA method to compare the configurational solutions of the research objects at critical moments in different development stages, so as to reveal the dynamic changes and evolution laws in the servitization development process of manufacturing enterprises (Du & Jia, 2017).

6.4.2 Future outlook

Based on the TOE framework and the configurational perspective, this thesis reveals the multiple paths and driving mechanisms of the service-oriented transformation of the manufacturing industry. Although this study has made certain progress in theoretical explanation and empirical testing, considering the complexity, dynamics, and context-dependence of the service-oriented transformation phenomenon, there is still considerable room for expansion in future research. Building on the existing research, future work can be deepened from four dimensions: temporal evolution, contextual boundaries, endogenous interaction, and consequence effects.

Firstly, break through the static cross-sectional observation and introduce a dynamic evolution perspective to analyze the temporal laws of transformation. Although existing studies can effectively identify the structural characteristics of service-oriented transformation, they struggle to capture the dynamic evolution process of resource orchestration and capability building of enterprises during the transformation. Future research should focus on using dynamic methods such as longitudinal qualitative comparative analysis or time-series modeling to track the evolution trajectories of the configurations of technological, organizational, and environmental elements of enterprises at different life-cycle stages. By introducing the time dimension, it is necessary to explore in depth how enterprises dynamically adjust the configuration of their antecedent conditions in response to external environmental changes, thereby revealing the dynamic evolution mechanism of the service - oriented transformation of the manufacturing industry from "quantitative accumulation" to "qualitative leap".

Secondly, expand geographical and institutional boundaries and initiate cross - regional and cross - national contextual comparative studies. This study is mainly based on the practical context of the manufacturing industry in Shandong Province, which provides a sample for understanding the transformation logic in a specific context but also highlights the necessity of future research expansion. To enhance the universality of the theory, future research should break the single - region limitation, extend the scope to high - tech and light - manufacturing agglomeration areas such as the Yangtze River Delta and the Pearl River Delta, and further initiate cross - national comparative studies. The focus should be on how the institutional environment, as a higher - order contextual variable, reshapes the configuration of technological, organizational, and environmental conditions. Through multi-context comparison, clarify the differential shaping effects of different institutional logics and regional industrial characteristics on service - oriented paths.

Thirdly, refine the heterogeneity dimensions of the samples and verify the path adaptation under different industrial attributes and enterprise scales. To overcome the inductive bias that may arise from a single - type sample, future research should significantly enhance the diversity and coverage of samples. On the one hand, attention should be paid to the heterogeneity of industrial attributes, and in-depth analysis should be conducted on the essential differences in technological requirements and organizational change difficulties among different industries to verify the applicable boundaries of the configurational paths in different industrial categories. On the other hand, small and medium-sized enterprises and multinational manufacturers should be included in the research scope. The resource constraints faced by small and medium - sized enterprises and the global value - chain coordination faced by multinational enterprises may give rise to completely different service-oriented driving logics. Through empirical investigations of diversified samples, the unique laws of different types of enterprises in service - oriented transformation can be more precisely identified, providing a broader scientific basis for formulating differentiated strategies.

Lastly, deepen the coverage of the theoretical model and analyze the deep - seated interaction and endogenous mechanism among multi - dimensional elements. The TOE model constructed in this paper selects representative key conditions. Future research can further improve the theoretical framework by considering soft elements such as organizational culture and entrepreneurial spirit to enhance the explanatory power of the model. At the same time, it is necessary to go beyond the one - way impact analysis of each conditional variable on the result and conduct in - depth analysis of the coupling relationship and interaction mechanism among the elements within the model. By combining longitudinal case studies or mixed research methods, explore in depth the internal interaction mechanism of mutual dependence and restriction among the elements, and construct a more inclusive, interactive, and explanatory theoretical system for the service - oriented transformation of the manufacturing industry

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Annex

Sample enterprise directory

No.	Enterprise code	Enterprise Name	No.	Enterprise code	Enterprise Name
1	338	潍柴动力	105	300653	正海生物
2	423	东阿阿胶	106	300677	英科医疗
3	488	晨鸣纸业	107	300690	双一科技
4	599	青岛双星	108	300699	光威复材
5	639	西王食品	109	300779	惠城环保
6	677	恒天海龙	110	300786	国林环保
7	680	山推股份	111	300801	泰和科技
8	726	鲁泰 A	112	300821	东岳硅材
9	756	新华制药	113	300840	酷特智能
10	811	烟台冰轮	114	300848	美瑞新材
11	822	山东海化	115	300918	南山智尚
12	830	鲁西化工	116	300950	德固特
13	869	张裕 A	117	300993	玉马遮阳
14	880	潍柴重机	118	301020	密封科技
15	915	山大华特	119	301022	海泰科
16	951	中国重汽	120	301035	润丰股份
17	957	中通客车	121	301069	凯盛新材
18	977	浪潮信息	122	301149	隆华新材
19	1207	联科科技	123	301158	德石股份
20	1219	青岛食品	124	301188	力诺特玻
21	1260	坤泰股份	125	301199	迈赫股份
22	1300	三柏硕	126	301206	三元生物
23	2026	山东威达	127	301209	联合化学
24	2073	软控股份	128	301281	科源制药
25	2078	太阳纸业	129	301296	新巨丰
26	2083	孚日股份	130	301439	泓淋电力
27	2088	鲁阳股份	131	600022	山东钢铁
28	2094	青岛金王	132	600060	海信电器
29	2107	沃华医药	133	600076	青鸟华光
30	2111	威海广泰	134	600219	南山铝业
31	2117	东港股份	135	600308	华泰股份
32	2193	山东如意	136	600309	万华化学
33	2237	恒邦股份	137	600319	亚星化学
34	2241	歌尔声学	138	600336	澳柯玛
35	2242	九阳股份	139	600426	华鲁恒升
36	2248	华东数控	140	600448	华纺股份
37	2254	泰和新材	141	600529	山东药玻
38	2270	法因数控	142	600579	天华院
39	2283	天润曲轴	143	600586	金晶科技
40	2286	保龄宝	144	600587	新华医疗

No.	Enterprise code	Enterprise Name	No.	Enterprise code	Enterprise Name
41	2330	得利斯	145	600600	青岛啤酒
42	2339	积成电子	146	600690	青岛海尔
43	2353	杰瑞股份	147	600727	鲁北化工
44	2355	兴民钢圈	148	600735	新华锦
45	2363	隆基机械	149	600760	中航黑豹
46	2374	丽鹏股份	150	600784	鲁银投资
47	2376	新北洋	151	600789	鲁抗医药
48	2379	宏创控股	152	600882	华联矿业
49	2382	蓝帆医疗	153	600955	维远股份
50	2408	齐翔腾达	154	600960	渤海活塞
51	2469	三维工程	155	600966	博汇纸业
52	2470	金正大	156	601058	赛轮金宇
53	2476	宝莫股份	157	601163	三角轮胎
54	2481	双塔食品	158	601678	滨化股份
55	2498	汉缆股份	159	601966	玲珑轮胎
56	2521	齐峰新材	160	603021	山东华鹏
57	2526	山东矿机	161	603026	石大胜华
58	2537	海立美达	162	603029	天鹅股份
59	2545	东方铁塔	163	603086	先达股份
60	2580	圣阳股份	164	603102	百合股份
61	2581	万昌科技	165	603113	金能科技
62	2588	史丹利	166	603151	邦基科技
63	2595	豪迈科技	167	603182	嘉华股份
64	2598	山东章鼓	168	603187	海容冷链
65	2643	烟台万润	169	603217	元利科技
66	2655	共达电声	170	603278	大业股份
67	2671	龙泉股份	171	603279	景津环保
68	2675	东诚药业	172	603367	辰欣药业
69	2726	龙大肉食	173	603536	惠发股份
70	2768	国恩股份	174	603577	汇金通
71	2805	丰元股份	175	603586	金麒麟
72	2810	山东赫达	176	603612	索通发展
73	2838	道恩股份	177	603638	艾迪精密
74	2871	伟隆股份	178	603639	海利尔
75	2890	弘宇股份	179	603739	蔚蓝生物
76	2891	中宠股份	180	603755	日辰股份
77	2899	英派斯	181	603779	威龙股份
78	2921	联诚精密	182	603798	康普顿
79	2984	森麒麟	183	603856	东宏股份
80	3022	联泓新科	184	603858	步长制药
81	3033	征和工业	185	605001	威奥股份
82	3042	中农联合	186	605006	山东玻纤
83	300001	特锐德	187	605016	百龙创园
84	300099	尤洛卡	188	605100	华丰股份
85	300105	龙源技术	189	605198	德利股份
86	300110	华仁药业	190	605567	春雪食品
87	300121	阳谷华泰	191	605589	圣泉集团

No.	Enterprise code	Enterprise Name	No.	Enterprise code	Enterprise Name
88	300175	朗源股份	192	688002	睿创微纳
89	300185	通裕重工	193	688021	奥福环保
90	300214	日科化学	194	688035	德邦科技
91	300224	正海磁材	195	688087	英科再生
92	300233	金城医药	196	688136	科兴制药
93	300243	瑞丰高材	197	688139	海尔生物
94	300285	国瓷材料	198	688161	威高骨科
95	300308	中际装备	199	688190	云路股份
96	300321	同大股份	200	688309	恒誉环保
97	300343	联创节能	201	688363	华熙生物
98	300391	康跃科技	202	688455	科捷智能
99	300423	鲁亿通	203	688501	青达环保
100	300443	金雷风电	204	688556	高测股份
101	300479	神思电子	205	688557	兰剑智能
102	300569	天能重工	206	688663	新风光
103	300583	赛托生物	207	688677	海泰新光
104	300594	朗进科技	208	688681	科汇股份