Policy Simulation Optimization Research on Digital Ecology Construction of Small and Medium Manufacturing Industries in Guangdong

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Abstract. This study presents the construction of a digital ecological policy simulation optimization model using system dynamics model, mathematical modeling, and computer simulation methods. The digital ecology in Guangdong Province exhibits a notable trajectory of rapid growth. However, the system is subject to an inverted U-shaped moderating effect from competitive pressure. Specifically, an increase in competitive pressure results in an initial rise followed by a subsequent decline in the growth of digital business cultivation. Moreover, the integration and fusion of digital businesses experience accelerated growth under conditions of heightened competitive pressure. According to these findings, it is suggested that the government should establish consistent policies, offer financial assistance, create regulatory structures, and nurture skilled individuals to facilitate the digitalization of small and medium-sized manufacturing sectors. Additionally, it is recommended to enhance the collaboration and cooperation within the industrial network to encourage the development and improvement of the digital infrastructure.

Keywords: Digital ecology; Small and medium-sized manufacturing industry; Policy simulation optimization; System dynamics model; Guangdong province

1 Introduction

The advancement of digital technologies has increased the level of connectedness and integration between organizations and industries, facilitating the exchange of innovative activities that transcend borders and establish interdependencies akin to natural ecosystems (Wang, 2021) [1]. In their study, Hein et al. (2019) [2] suggested that the digital platform ecosystems consist of three fundamental elements: platform ownership, value-creating processes, and complementor autonomy. Digital platforms and their associated ecosystems offer SMEs a wealth of opportunities (Nambisan & Baron, 2019) [3]. These environments facilitate the exchange and generation of knowledge, which in turn fuels the process of digitalization activities (Bereznoy et al., 2021) [4]. In order to reduce the disparity in digital transformation across firms, the government may do this by developing a well-designed policy framework. However, the frequent revisions to policies result in an increase in ambiguity

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about the policies (Geng et al., 2023) [5]. Hence, manufacturing companies have to fully use the government's favorable policies to bolster their digitalization skills, thereby fortifying their competitiveness in the digital economy age (Zhao et al., 2023) [6].

2 Literature Review

Digital ecology refers to an online platform that enables communication and sharing across different groups, fosters innovation and information for industrial growth, and encourages the integration and restructuring of industrial ecosystems (Yu & Li, 2021) [7]. The authors Yu et al. (2022)[8] developed a model to assess the maturity of small and medium-sized manufacturing digital ecosystems. They highlighted that these ecosystems are created by combining digital technologies and data-driven methods to improve processes and enable real-time monitoring of assets.

The Technology–Organization–Environment (TOE) model divides technology, organization, and environment as the primary determinants that impact the acceptance of technological advancements. To effectively implement digital technologies, manufacturing firms need to integrate their technological capabilities with organizational preparedness and external environmental influences (Cho et al., 2021[9]; Malik et al., 2021[10]). Li et al., (2022)[11] aims to analyze the factors influencing digital innovation in small and medium-sized manufacturing enterprises. It focuses on the impact of technology, organization, and environment on innovation using the TOE framework. The study proposes four strategies to achieve digital innovation, highlighting the importance of integrating multiple factors.

System Dynamics (SD) and Vensim simulation tools are extensively used across several domains to enhance policy modeling and decision-making procedures. The system dynamics models facilitate evidence-based decision-making by offering a platform for hypothesis testing and examining the consequences of various policy options. They possess the capability to enhance comprehension, optimize policy interventions, and aid in the decision-making process (Kechagias et al., 2021[12]; Babagana Modu et al., 2020[13]; Milad Mousavian et al., 2020[14]).

Pedro et al., (2023) [15] conducted a comparative analysis of the digital transformation plans for manufacturing in the EU27. The study reveals that government initiatives have mostly concentrated on allocating funds, establishing regulatory frameworks, and promoting the development of human capital. (Wen et al., 2022) [16] highlighted the need for developing nations to create adaptable strategies that encourage creative manufacturing growth and decrease reliance on foreign technology. These measures should prioritize the promotion of sustainable business practices rather than embracing policies that may hinder development.

By reviewing relevant literature, it is evident that the research on the digital ecology of the manufacturing industry is insufficiently thorough. Additionally, the analysis of policy regulation and optimization lacks a comprehensive examination of the establishment of a digital ecology for small and medium-sized manufacturing industries. Thus, this study utilizes the TOE framework theory to develop a policy simulation and optimization model of digital ecology for small and medium-sized manufacturing industries. An empirical study is conducted in Guangdong Province as an example, with the goal of addressing research gaps and providing practical value.

3 System Dynamics Modeling of Digital Ecology in Small and Medium-Sized Manufacturing Industries

3.1 Model Underlying Assumptions and System Flow Diagrams

This study establishes the following fundamental assumptions about the research model, drawing upon the findings of (Liu., 2021) [17] and (Guo et al., 2023) [18]. Firstly, the digital environment of small and medium-sized manufacturing industries is an ongoing and gradual process of behavior. Secondly, the development of digital businesses is primarily influenced by technological factors, while the integration and fusion of digital businesses are primarily influenced by organizational factors and the level of competitive pressure experienced by the enterprise. The level of pressure experienced by businesses in a competitive environment will contribute to a decrease in the rate of digital business development and the elimination of digital business integration and fusion. Additionally, there is a causal relationship between digital business development and digital business integration and fusion through the application and sharing of knowledge. Furthermore, in order to simplify the simulation, the issue of time lag delay is not taken into account.

The graphic in Figure 1 illustrates the system flow of the digital ecology in the small and medium-sized manufacturing business. It includes two stock variables, four flow variables, nine auxiliary variables, one constant variable, and one random variable. The system flow diagram illustrates the interconnections among various components involved in the implementation of the digital infrastructure within the small and medium-sized manufacturing sector. It encompasses the structural attributes of the system as well as its dynamic qualities.

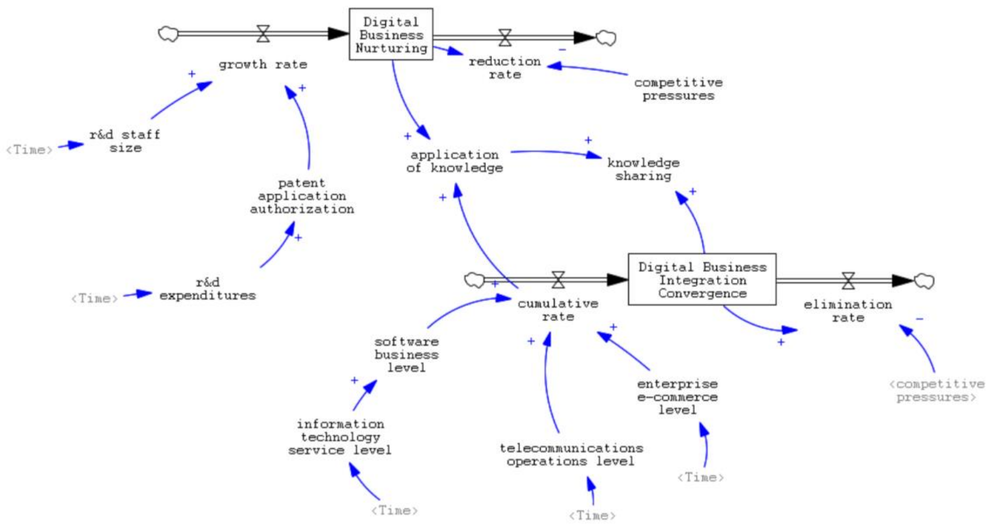

Figure 1. Digital ecosystem flow diagram for SME manufacturing.

3.2 Equation Design and Description

The initial parameters for the digital eco-system of small and medium-sized manufacturing industries were established based on the causality of variables and sample data for correlation and regression analysis. The existing research literature (Guo et al., 2023[18]; Wang et al., 2021[19]) was consulted to guide the selection of relevant parameters. The study focused on the period from 2012 to 2025, with a time step of 1 year. The variable settings and equation design parameters are presented in Table 1.

Table 1. Variable settings and equation expression design.

Variable	Equation design
Digital Business Nurturing	Digital Business Nurturing=INTEG (growth rate-reduction rate)
growth rate	growth rate=0.7*r&d expenditures+0.3*r&d staff size
reduction rate	reduction rate=IF THEN ELSE (competitive pressures≥0.75, Digital Business Nurturing *0.03, Digital Business Nurturing *0.01)
r&d staff size	Input time-series data for 2012-2022
r&d expenditures	Input time-series data for 2012-2022
patent application authorization	0.0181*r&d expenditures-275163
Digital Business Integration Convergence	Digital Business Integration Convergence=INTEG (cumulative rate-elimination rate)
cumulative rate	cumulative rate=0.6*software business level+0.2*telecommunications operations level+0.3*enterprise e-commerce level
elimination rate	elimination rate=IF THEN ELSE (competitive pressures≥0.75, Digital Business Integration Convergence*0.03, Digital Business Integration Convergence*0.01)
information technology service level	Input time-series data for 2012-2022
software business level	software business level=1.0315*information technology service level+0.0383
telecommunications operations level	Input time-series data for 2012-2022
enterprise e-commerce level	Input time-series data for 2012-2022
application of knowledge	0.6*Digital Business Nurturing +0.4*cumulative rate
knowledge sharing	0.6*application of knowledge+0.4*Digital Business Integration Convergence
competitive pressures	Set as a random variable between [0,1]

4 Simulation Results Analysis

4.1 Illustration of the Simulation Model's Primary Variables

Dynamics of the system Using the logical line of the model, important variables are chosen for examination in the systemic modeling of the digital ecology of Guangdong Province's small- and medium-sized manufacturing sector. The simulation model incorporates several data sources, such as the Statistical Report on the Development Status of the Internet in China, Guangdong Statistical Yearbook, and other relevant pertinent information.

Figure 2 depicts the development trajectory of digital business cultivation. The model simulation results indicate that, in recent years, there has been a rapid growth trend in digital business cultivation, with a reasonably consistent growth rate. In comparison to 2023, the growth rate of digital business cultivation in 2025 is around 32.36%.

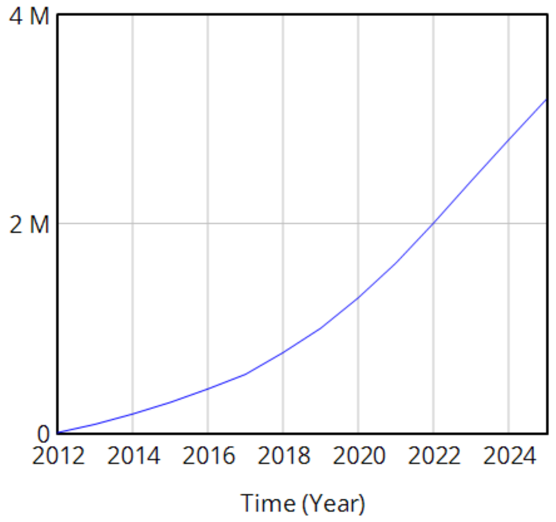

Figure 2. Results of simulating digital business nurturing in SME manufacturing.

Figure 3 illustrates the trajectory of digital business integration and convergence, while the model simulation findings indicate that the digital business integration and convergence index is projected to reach a value of 3.65 by the year 2025, reflecting a growth of 17.34% compared to the previous year, 2023. The manufacturing digital ecology has a robust trajectory of advancement and is poised to emerge as the primary catalyst for economic growth and industrial change in Guangdong Province.

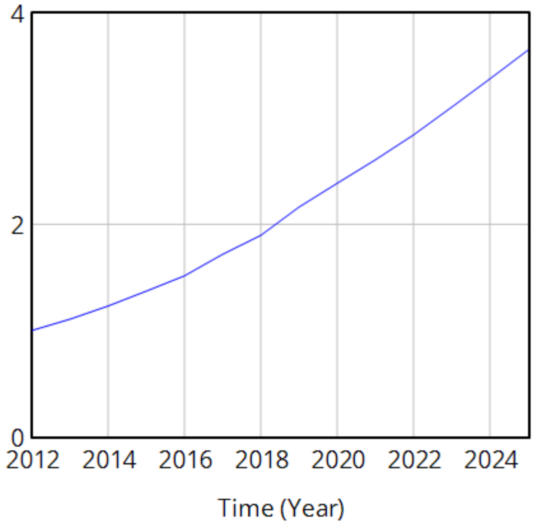

Figure 3. Results of simulating digital business integration convergence in SME manufacturing.

4.2 Experiment with Control Variable Simulation

The research by Guo et al. (2023) [18] classifies the external adjustable variable of the system as competitive pressure, which is divided into two levels with matching values of 0.5 and 0.8. Examine the evolving dynamics of how competitive pressure affects the development and integration of digital business in small and medium-sized industrial sectors.

The progressive trajectory of digital business development in small and medium-sized industrial businesses is shown in Figure 4. From 2018 onwards, curve 2 has progressively increased and surpassed curve 1, particularly after 2022, indicating a rapid development pattern. This suggests that when competitive pressure intensifies, the growth of digital businesses exhibits a pattern of initial rise followed by subsequent decline. Furthermore, the competitive pressure has a moderating influence on the system, following an inverted U-shaped pattern. Simultaneously, organizations in the intermediate and advanced phases of growth have a larger propensity to preserve their current competitive advantages amidst heightened competitive pressures, rather than pursuing additional advancements in their digital operations via the expansion of their knowledge base.

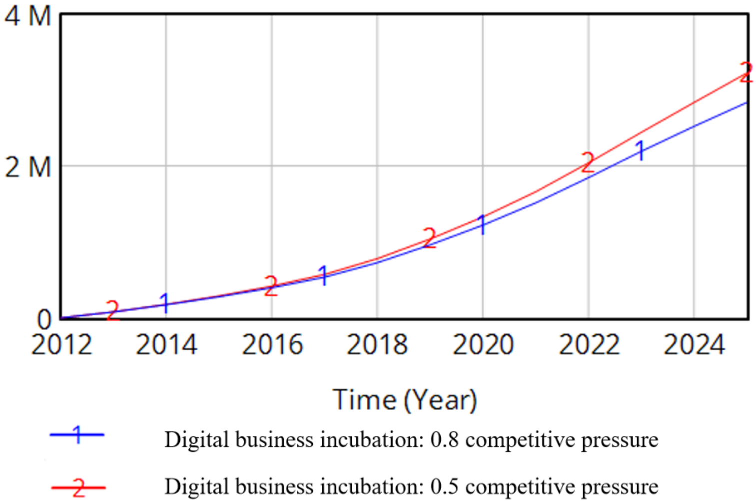

Figure 4. Simulation outcomes of growing a digital business nurturing at various competitive pressure levels.

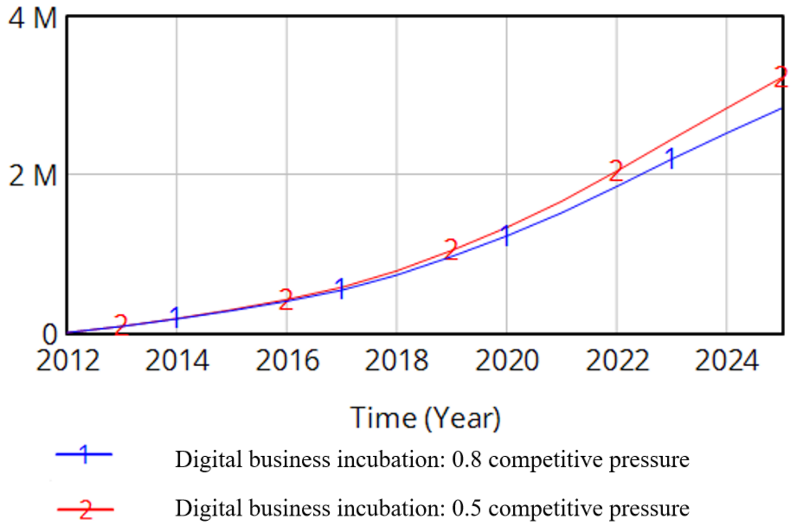

Figure 5. Simulation outcomes of growing a digital integration convergence at various competitive pressure levels.

Figure 5 depicts the progressive pattern of incorporating and merging digital business practices in small and medium-sized industrial sectors. Curve 1 exhibits a period of stagnant development throughout its early phase, followed by a progressive acceleration starting from 2014, particularly after 2020, when it surpasses curve 2 by a large margin. These findings indicate that companies in the digital business integration convergence industry are prioritizing technical innovation and optimizing their business models in response to increased competitive challenges, resulting in their fast expansion. In contrast, when subjected to relatively modest levels of competitive pressure, the convergence of digital business integration, although experiencing a steady growth trajectory, does not exhibit the same rate of growth as seen under high levels of competitive pressure.

5 Conclusions

This research thoroughly examines the digital ecology of small and medium-sized manufacturing businesses in Guangdong Province, focusing on system dynamics. A model is developed to simulate and analyze this environment. The analysis reveals that the cultivation of digital businesses exhibits a notable trajectory of fast development. However, when competitive pressure intensifies, the growth pattern undergoes a pattern of initial increase followed by subsequent decline. This observation highlights the presence of an inverted U-shaped moderating influence of competitive pressure on the cultivation of digital businesses. The acceleration of digital business integration and convergence may be attributed to heightened competitive pressures, prompting firms to prioritize technology innovation and optimize their business models.

This research offers recommendations for government decision-making in light of the aforementioned results. Initially, it is important for the government to develop enduring and consistent support policies in order to prevent repeated policy changes that amplify uncertainty. Furthermore, the government may facilitate the digitalization of small and medium-sized industrial sectors via the provision of financial assistance, establishment of regulatory structures, and fostering of skilled personnel. Furthermore, it is imperative for the government to prioritize the comprehensive advancement of the industrial landscape, enhance the integration and collaboration across diverse sectors, and facilitate the establishment and enhancement of the digital infrastructure.

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