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Exploration of the Driving Path of Digital and Intelligent Transformation of Automobile Manufacturing Enterprises

-- Based on the Dynamic QCA Analysis

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ABSTRACT

The digital economy is a major trend in the global economic development,in such an economic wave,intelligent manufacturing has become a new highland of competition.It has become the trend of The Times to take intelligent manufacturing as the main development direction and promote the upgrading of manufacturing industry to digitalization and intelligence.Based on the TOE analysis framework, this paper takes 27 automobile manufacturing enterprises from 2018 to 2022 as the research object, uses R-Studio software to carry out dynamic QCA analysis, and explores the path of mathematical transformation of automobile manufacturing enterprises driven by the antecedent conditions of ' technology-organization-environment ' dimension from the perspective of configuration. The research shows that any single antecedent condition cannot independently become a necessary condition to drive the digital intelligence transformation of automobile manufacturing enterprises.The level of digital intelligence transformation of high-level enterprises is affected by the ' multiple concurrency ' of six conditions : intelligent production, technology R & D capability, knowledge talent investment, management transformation planning, government support and digital innovation environment, and has formed three types of configuration modes : digital technology + R & D environment-driven, digital technology + organizational planning-driven and digital technology + high-end talent-driven.The technological R & D capability in the technical dimension and the digital innovation environment in the environmental dimension are the core reasons for the failure of the digital intelligence transformation of the automobile manufacturing industry. Based on the research conclusions, this paper puts forward relevant policy suggestions to promote automobile manufacturing enterprises to accelerate the transformation of digital intelligence from the aspects of strengthening the application of configuration coordination thinking, grasping the investment in technology research and development, and the government 's assistance in digital environment optimization.

KEYWORDS

Digital intelligence transformation; Dynamic QCA; Automobile manufacturing enterprise; Analysis of necessary conditions

1. INTRODUCTION

General Secretary Xi pointed out in the party's 20th annual report: " We will promote the deep integration of digital technology and the real economy, and enable the transformation and upgrading of traditional industries [1].As an important pillar of the national economy, the automobile manufacturing industry not only undertakes the important task of driving the development of related industries, but also supports the foundation of the country 's comprehensive national strength. It is also the commanding height of industrial competition among countries. It is a great power to participate in the global industrial division of labor and compete for the most upstream of the global industrial chain. In 2023, the Ministry of Industry and Information Technology and other seven departments jointly issued the " Work Programme for Steady Growth of the Automotive Industry (2023-2024), " which proposed measures to stabilize automobile consumption, expand the promotion of new energy vehicles, stabilize fuel vehicle consumption and stabilize the industrial chain supply chain [2]. With the continuous development of the policy effect, the output value of the automobile manufacturing industry continues to expand. However, in some key technologies and chips, China still faces the problems of insufficient production and patent control.

The transformation of information technology and its reconstruction of industry have a profound impact on the form and quality of manufacturing development. Promoting the transformation and upgrading of manufacturing industry with intelligent manufacturing as the main direction has become a new requirement under the background of digital economy.Under the double test of old problems and new risks in the manufacturing industry, the automobile manufacturing industry needs to take the initiative to carry out digital and intelligent transformation and change if it wants to seize the opportunity of digital transformation to reconstruct the global manufacturing competition pattern and solve the old and new problems. Digital intelligence transformation is a key action for manufacturing enterprises to rejuvenate enterprises under environmental uncertainty. It is also a " compulsory course " related to survival and long-term development [3], and an important means to solve the current "dilemma" of automobile manufacturing industry development.Although the government and academia are strongly advocating the digital intelligence transformation of manufacturing enterprises, hoping that Chinese manufacturing enterprises will seize the unprecedented changes in a century, reshape the global manufacturing value chain, and compete for the right to speak [4]. However, the digital intelligence transformation itself is a long-term task, which is not only affected by the complex environment, but also faces great challenges or even failures due to the lack of prior experience. Therefore, how to promote the successful transformation of the automobile manufacturing industry to achieve digital intelligence is a hot issue in the current society.

According to the theory of complex system view, Kiel et al. [5] pointed out that the transformation of manufacturing enterprises to the direction of number intelligence is a process and a systematic project. This project can promote the transformation of production and operation mode of enterprises, and then promote the improvement of operation efficiency of enterprises, and may even find new production and operation direction for enterprises.Therefore, only considering the driving effect of a single factor, it is obviously impossible to effectively analyze the interaction between multiple factors and its complex causal relationship with the transformation of enterprise number intelligence [6].

Therefore, based on the TOE analysis framework, this paper takes automobile manufacturing enterprises as the research object, uses the panel data from 2018 to 2022, and uses the dynamic QCA research method to analyze the complex causal relationship between the level of digital intelligence transformation of automobile manufacturing enterprises in China and its influencing factors. From the perspective of configuration, this paper analyzes the path of digital intelligence transformation of automobile manufacturing enterprises driven by the antecedent conditions of ' technology-organization-environment' dimension, in order to provide theoretical support and guidance for the practical exploration of digital intelligence transformation of automobile manufacturing enterprises in China.

2. THEORETICAL BASIS AND RESEARCH FRAMEWORK

2.1. Research Framework

The TOE framework does not specify the specific explanatory variables of the three dimensions of technology, organization and environment in detail. It has strong flexibility and operability [7] and has been widely used in strategic change, digital transformation, digital transformation and other aspects of the adoption and practice process research. Automobile manufacturing enterprises have the characteristics of long industrial chain, strong driving force and high professional and technical level. Affected by the comprehensive influence of the antecedent conditions of technology, organization and environment, it is the result of the linkage matching of 'technology(T) - organization(O)-environment (E)'. Therefore, from the perspective of configuration, the internal and external factors of technology, organization and environment are considered at the same time, and the relationship between the antecedent configuration and the digital intelligence transformation of automobile manufacturing enterprises is explored, so as to provide scientific theoretical basis and decision-making reference for the digital intelligence transformation of automobile manufacturing enterprises.

2.1.1. Technology Dimension

Research based on the perspective of resource-based theory points out that digital technology, as a unique resource of enterprises, [8] is a key factor in the transformation of enterprises ' number intelligence. The integration with automobile manufacturing enterprises can accelerate the transformation to the direction of number intelligence, effectively manage the process of number intelligence transformation, and then provide guarantee for the transformation of enterprises ' number intelligence. Based on the research results of Yang Hong [9] and Lu Chi [10], this paper decomposes the factors of technical dimension into two secondary conditions of intelligent production and technology research and development ability from the perspective of input and output, so as to explore the driving effect of technical factors on the digital intelligence transformation of automobile manufacturing enterprises.

The new generation of digital technology represented by cloud computing, Internet of things and big data has infinite possibilities and is a powerful engine for the digital transformation of automobile manufacturing enterprises. Digital technology is an important means for enterprises to carry out future technological innovation and can accelerate the progress of digital transformation [11]. Under the background of intelligent development of manufacturing industry, the investment of enterprises in intelligent equipment can show the intelligent level of enterprise production and manufacturing. The automobile manufacturing enterprise itself has a long industrial chain, and the professional level of equipment and facilities is high. The automobile products are produced on a large-scale and specialized production line, so the ability of enterprises to apply digital technology to production and manufacturing links has higher requirements. Therefore, advanced intelligent manufacturing workshops are the key resources and important basis for supporting automobile manufacturing enterprises to accelerate the transformation of digital intelligence and achieve high-quality development [12].

Technological R&D achievements can reflect the ability of enterprises to transform into digital intelligence. As a technology-intensive industry, automobile manufacturing industry is an important representative of industrial output and the core of industry competition. Digital patents can not only reflect the technological innovation and design R&D capabilities of automobile manufacturing enterprises, but also provide technical support for the transformation of enterprise digital intelligence, making the transformation of enterprise digital intelligence more sustainable and robust. Therefore, intelligent production and technology research and development capabilities are an important prerequisite for automobile manufacturing enterprises to carry out digital transformation.

2.1.2. Organization Dimension

In the organizational innovation of automobile manufacturing enterprises, knowledge innovation is a particularly important part. Based on the theory of knowledge innovation, knowledge innovation mechanism is a complex system composed of people, system, organization, technology and so on. The role of knowledge innovation mechanism in the digital transformation of automobile manufacturing enterprises is reflected in the whole internal and external circulation process of acquiring new knowledge and skills from outside the organization and digesting and absorbing knowledge and skills [10]. This paper divides the factors of organizational dimension into two secondary conditions : knowledge talent input and management transformation planning, so as to explore the driving effect of organizational factors on the digital intelligence transformation of automobile manufacturing enterprises.

From the perspective of talent input, the leading and supporting role of high-end talents in the process of digital intelligence transformation requires automobile manufacturing enterprises to invest a large number of high-level digital talents in the process of digital intelligence transformation. Therefore, a strong talent pool can continuously introduce external advanced knowledge and technology into enterprises by virtue of its own knowledge absorption capacity, promote the full utilization of various types of production factor resources, and help optimize the allocation of other production factors, so as to realize the long-term and sustainable transformation of digital intelligence. From the perspective of management, automobile manufacturing enterprises will face multi-faceted challenges of market demand, industry competition and government policies in the process of digital intelligence transformation. These challenges require management to have ultra-high strategic sensitivity in the process of digital intelligence transformation, so as to seize the opportunities of digital intelligence transformation and achieve the goal of high-level digital intelligence transformation. According to the strategic choice theory and the upper echelons theory[16], the biggest challenge faced by enterprise managers in their work is to start from their own cognition, according to their own work and problem handling methods, to identify the rich and complicated information, and finally make more effective decisions and strategic planning. The deeper the senior executives ' understanding of the transformation of enterprises ' digital intelligence, the clearer the prospect of realizing the high-quality development of enterprises, and the more effective the product intelligence, process intelligence, service intelligence and management intelligence of automobile manufacturing enterprises will be. Therefore, it can be seen that the input of knowledge talents and the transformation planning of management can effectively promote the internal advantages of the digital transformation of automobile manufacturing enterprises.

2.1.3. Environment Dimension

Environmental changes often directly affect the future development of enterprises [11]. The environmental school of strategic management theory emphasizes that the motivation of corporate strategic change mainly comes from the influence of the external environment [9]. An excellent business environment can not only bring the same excellent resources and services to enterprises, but also stimulate enterprises to adjust their strategies to better adapt to changes in the external environment. In this paper, the factors of environmental dimension are refined into two secondary conditions: government support and digital innovation environment, so as to explore the driving effect of environmental factors on the digital intelligence transformation of automobile manufacturing enterprises.

The excellent business environment provides a good development foundation and operational vitality for the digital intelligence transformation of automobile manufacturing enterprises. Among them, the financial support from the government is an important guarantee for promoting the development of intelligent manufacturing mode and the transformation of automobile manufacturing enterprises to digital intelligence [11]. The government 's subsidy to enterprises is an important external driving factor affecting the digital transformation of manufacturing enterprises. With China 's actions such as helping specialized new giants and intelligent manufacturing pilot demonstration enterprises, government subsidies have played an increasingly significant role in promoting the process of digital transformation of manufacturing enterprises [17]. As a policy means to encourage enterprises to develop intelligent manufacturing, government subsidies can not only reduce the cost and risk of transformation in the process of digital intelligence transformation, but also enable enterprises to enhance their ability to cope with risk crisis, so as to stabilize their determination in the process of digital intelligence transformation. It will also transmit a stronger signal of transformation to the investment community, so that more investors can help automobile manufacturing enterprises to successfully implement digital intelligence transformation.

R&D environment is the basis of enterprise innovation activities. A good R&D environment can stimulate the innovation enthusiasm and creativity of R&D personnel and improve innovation efficiency. Innovation is the core driving force for the sustainable development of enterprises, especially in technology-intensive industries. The strength of R&D capabilities is directly related to the competitiveness and market position of enterprises. The R&D expenditure of industrial enterprises above designated size can not only reflect the intensity of R&D and innovation investment in the regional industry of automobile manufacturing enterprises, but also is one of the important indicators to measure the digital environment of enterprises. It can also stimulate the enthusiasm of other manufacturing enterprises to move towards digital intelligence transformation through ' peer effect ' [9], and help the digital and intelligent coordinated development of China 's automobile manufacturing industry. It can be seen that government support and digital innovation environment play an important role in the intelligent development of automobile manufacturing enterprises.

From the perspective of complex system theory, as a complex systematic project, the evolution and development of digital intelligence transformation activities of automobile manufacturing enterprises are the result of the dynamic synergy of technological change, organizational behavior and environmental stimulation. Therefore, through the above analysis, this paper constructs a theoretical framework model of digital intelligence transformation of automobile manufacturing enterprises based on TOE analysis framework, as shown in Figure 1.

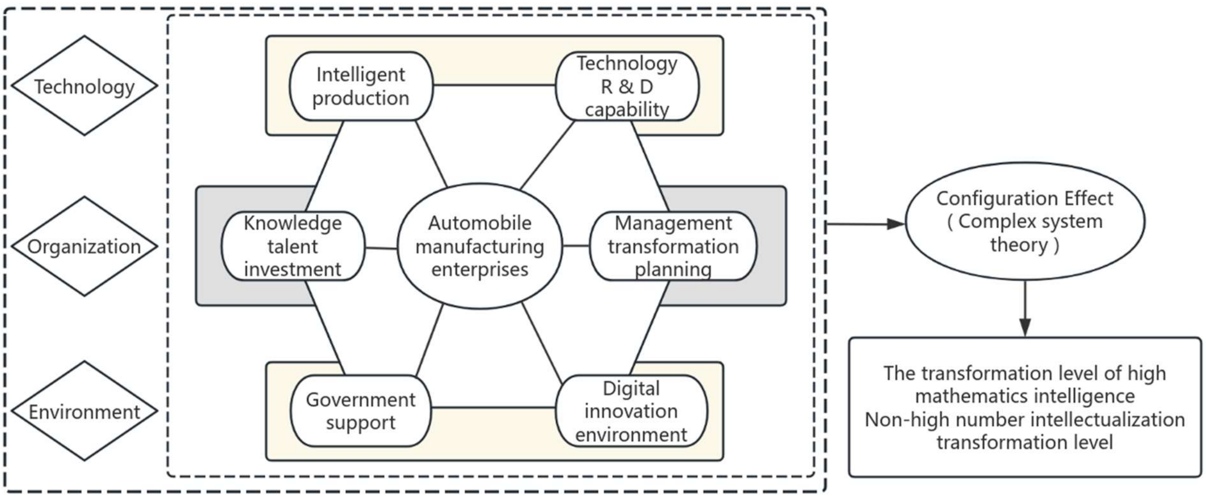

Figure 1. Theoretical framework.

2.2. Methodology (Dynamic QCA)

The process of digital intelligence transformation of automobile manufacturing enterprises is a dynamic evolution process with continuous and long-term characteristics, in which there is a complex causal relationship. QCA is a qualitative analysis method that can analyze the linkage combination and synergistic effect between multiple factors, and is committed to analyzing the complex causal relationship between multiple variables. Du Yunzhou [18] and others pointed out that QCA is suitable for analyzing this complex causal relationship. Due to the complexity of the institutional configuration problem, the static QCA method has a time cross-section problem when dealing with panel data, which may lead to inaccurate analysis results. In view of this, this paper adopts the dynamic QCA method based on the panel data set theory method proposed by Garcia-Castro and

Ariño [19] to solve the problem. Among them, dynamic QCA can better identify the time effect and individual effect of institutional configuration by further dividing consistency into summary consistency, inter-group consistency and intra-group consistency [20]. The distance between group consistency and intra-group consistency represents the time heterogeneity and individual heterogeneity of panel data, which can indicate whether the dominant sample data is time effect or cross-sectional effect, and then determine whether the results obtained by QCA method are accurate. With the help of R-Studio software, this paper realizes the panel data analysis of QCA.

2.3. Data Source

This paper refers to the screening method of Luchi [10] and takes the listed companies of automobile manufacturing industry as the research object. After preliminary screening, a total of 80 listed companies were selected to meet the conditions. After excluding incomplete data, ST and ST * company samples, 27 listed companies were finally obtained. The data in this paper come from China Statistical Yearbook, statistical yearbooks of provinces (autonomous regions and municipalities directly under the central government), CSMAR database and annual reports of listed companies. China began to widely implement the transformation of digital intelligence in 2017 [10]. Considering that the effect of enterprise digital intelligence transformation was difficult to appear in that year, and the availability of data, the selection period of sample data is 2018-2022.

2.4. Variable Setting and Description

2.4.1. Result Variables

Table 1. Digital intelligence transformation level evaluation index system

First grade indexes	Second grade indexes	Third grade indexes	Index attribute
A Digital intelligent basic equipment support	A^1Network infrastructure support	A^{11}Number of mobile base station construction	+
		A^{12}Number of Internet broadband access users	+
	A^2Digital intelligence application	A^{21}Intelligent equipment investment	+
		A^{22}Intelligent Software Applications	+
B Product number intelligence level	B^1Digital intelligence R&D innovation	B^{11}Automobile-related patent grants	+
		B^{12}R&D investment intensity of automobile industry	+
		B^{13}R&D investment in automobile industry	+
		B^{14}Enterprise r&d investment intensity	+
		B^{15}Enterprise r&d investment	+
C Digital intelligence strategy change	C^1Digital intelligence management	C^{11}Cost rate during sales	-
		C^{12}Fixed assets turnover ratio	+
		C^{13}Rate of stock turnover	+
		C^{14}Assets-liability ratio	-
		C^{15}Total revenue growth rate	+
		C^{16}labor productivity	+
		C^{17}Lerner coefficient of individual stocks	+

(1) The level of digital intelligence transformation of automobile manufacturing enterprises. This paper draws on the measurement methods of scholars such as Fu Weizhong [21], Zhang Aegean [22] and Peng Yajie [23] on the effectiveness of digital transformation of manufacturing industry, and considers the availability of data. From the three dimensions of digital intelligent infrastructure support, product digital intelligent level and digital intelligent strategic change, an evaluation index system of digital intelligent transformation level of automobile manufacturing enterprises with 16 indicators is constructed (see table 1). Then, the CRITIC-entropy method is used to weight each index, and then the level of digital intelligent transformation of automobile manufacturing enterprises is calculated.

2.4.2. Condition Variables

(1) Intelligent production (IP) . Constrained by the availability of data, referring to the research of Park and Mithas [14], the total balance of the original value of the electronic equipment and software accounts for the proportion of the total assets of the enterprise, indicating the degree of intelligent production.

(2) Technology R&D capability (TR&DC) . Referring to the practice of Wu Weiwei and Zhang Tianyi, [25] the number of invention patent applications of enterprises is selected as a measure of the technological R&D capability of enterprises, and the data are processed logarithmically after adding one.

(3) Knowledge talent input (KTI) . With reference to Yang Hong [9], the proportion of R & D personnel to the total number of employees at the end of the year is used to represent the input of knowledge talents.

(4) Management transformation planning (MTP) . Referring to Lu Chi [10] and Yang Hong [9] based on text analysis technology, with the help of the ' jieba ' participle library in python software, the part of ' management discussion and analysis ' in the annual report of the enterprise is queried. The keywords are as follows : digital intelligence, digitization, intelligence, artificial intelligence, digital portrait, intelligent manufacturing, industrial Internet, informatization, intelligent networking, intelligent platform, big data, data mining, data elements, Internet +, Internet of things, cloud computing, cloud services, Internet of things, cloud architecture.

(5) Government support (GS) . Referring to the measurement method of Wang Kemin et al. [26], the proportion of government subsidies to the main business income is selected to indicate the degree of government support for enterprises.

(6) Digital innovation environment (DIE) . Constrained by the availability of data, referring to Yang Hong [9], the sum of internal expenditure (basic research, applied research, experimental development, etc.) and external expenditure (expenditure on domestic research institutions, expenditure on domestic colleges and universities, expenditure on domestic enterprises, etc.) of R & D funds of industrial enterprises above designated size in the statistical year of the province (district, city) where the enterprise is located is expressed.

2.4.3. Variable Calibration.

Calibration is the process of assigning membership to the sample case set. Based on the practice of Du et al. [27] and the actual situation of the sample case, this paper sets 5 %, 50 % and 95 % quantiles of all continuous variables as three anchor points of complete non-membership, intersection and complete membership. At the same time, in order to avoid the configuration attribution problem that the case membership degree of the variable is exactly 0.5, the membership scores below 1 are added to 0.001 by referring to the practice of Fiss [28]. The calibration and descriptive statistics of each variable are as follows.

Table 2. Description of main variables and descriptive statistics.

Variables	Meaning of Variables	Descriptive analysis			
		Mean	Variance	Min	Max
DITL	Digital intelligence transformation level	0.1641	0.10027	0.04	0.59
IP	Intelligent production	0.2525	0.13546	0.04	0.73
TR & DC	Technology R & D capability	319.7778	515.96716	0	3555
KTI	Knowledge talent investment	15.4801	7.47898	4.13	44.49
MTP	Management transformation planning	0.0049	0.00310	0	0.02
GS	Government support	0.009	0.00941	0	0.05
DIE	Digital innovation environment	1465.4244	1016.5902	115	4411.9

Table 3. Variable calibration.

Research variables	Conditional variable	Calibration		
		Completely affiliated	Crossing point	Completely unaffiliated
Outcome variable	DITL	0.38069	0.13379	0.06108
Conditional variables	IP	0.48100	0.23823	0.08190
	TR & DC	1401.5	104	3
	KTI	27.948	14.4	5.84
	MTP	0.01025	0.00454	0.00083
	GS	0.02979	0.00574	0.00058
	DIE	3479.9	1445.7	160.62

3. RESULTS

3.1. Necessity Analysis of a Single Condition

When using panel data for QCA, the necessity of a single condition needs to meet three conditions at the same time, namely : the condition and its ' non-set ' summary consistency level is higher than 0.9, the summary coverage is greater than 0.5, and the consistency adjustment distance between groups and within groups is less than 0.2, indicating that the summary consistency accuracy is higher [19]. Table 4 reports the results of a single conditional necessity analysis. The summary consistency of the 6 conditions and their ' non-sets ' was less than the standard 0.9, but there were 3 cases in which the consistency adjustment distance between groups was greater than 0.2, and there might be a time effect.

Table 4. Necessary condition analysis of quantity.

Conditional variables	High-level of digital intelligence transformation				Low-level of digital intelligence transformation			
	Aggregate consistency	Aggregate coverage	BECONS adjusted distance	WICONS adjusted distance	Aggregate consistency	Aggregate coverage	BECONS adjusted distance	WICONS adjusted distance
IP	0.608	0.598	0.04058	0.14258	0.639	0.717	0.07536	0.53743
~IP	0.712	0.633	0.11303	0.11516	0.642	0.651	0.06086	0.47711
TR & DC	0.721	0.844	0.06956	0.16452	0.391	0.523	0.08695	0.78969
~TR & DC	0.593	0.461	0.14491	0.06581	0.884	0.783	0.03478	0.22484
KTI	0.703	0.685	0.06086	0.21388	0.583	0.648	0.11303	0.47711
~KTI	0.639	0.573	0.09274	0.09871	0.717	0.733	0.05217	0.40033
MTP	0.693	0.676	0.16520	0.44969	0.606	0.674	0.23766	0.44969
~MTP	0.665	0.597	0.25215	0.29614	0.709	0.725	0.15651	0.38388
GS	0.649	0.66	0.06376	0.43323	0.596	0.691	0.22896	0.42775
~GS	0.696	0.601	0.06086	0.27968	0.706	0.697	0.14781	0.32904
DIE	0.748	0.786	0.09274	0.30710	0.507	0.608	0.16230	0.59227
~DIE	0.627	0.527	0.12463	0.10968	0.821	0.788	0.05797	0.28517

Note: ' ~ ' denotes the ' non ' of a logical operation (the same below).

This needs further testing. Table 5 reports three combinations of causal relationships with inter-group consistency adjustment distances greater than 0.2. First, check the consistency and coverage of each year in these three cases, and identify that there is no case where the consistency is greater than 0.9 and the coverage is greater than 0.5, indicating that it does not constitute a necessary condition. In summary, it has been verified that any single antecedent condition cannot be a necessary condition to drive the digital intelligence transformation of automobile manufacturing enterprises.

Table 5. The data of BECONS adjust distance is greater than 0.2 in quality

Causal combination situation			Year				
			2018	2019	2020	2021	2022
Situation1	~MTP	consistency	0.823	0.814	0.706	0.554	0.502
	High-level	coverage	0.492	0.535	0.679	0.713	0.634
Situation2	MTP	consistency	0.495	0.468	0.679	0.739	0.705
	Low-level	coverage	0.825	0.77	0.707	0.586	0.581
Situation3	GS	consistency	0.42	0.593	0.617	0.651	0.749
	Low-level	coverage	0.74	0.716	0.685	0.65	0.677

3.2. Adequacy Analysis of Conditional Configuration

3.2.1. Pooled Results

The core of the QCA method is to analyze the influence of different combinations of conditions on the outcome variables. It is mainly based on the perspective of set theory to reveal the differential configuration formed by the coupling and linkage of influencing factors, and the adequacy level of the results caused by the configuration [29]. Based on the previous research and the actual situation, this paper finally selects the consistency level threshold of 0.8 [30], PRI of 0.75, and frequency of 1 to construct the truth table. The model covers 135 sample data. In R-Studio software, it is necessary to optimize the value algorithm. Considering that the research object is the intelligent representative of automobile manufacturing enterprises, the resource endowments between enterprises are quite different, and it is impossible to uniformly judge the effect of other antecedent conditions on the results. Therefore, in order to avoid inappropriate assumptions that may affect the comprehensiveness and scientificity of the results, this paper does not presuppose other antecedent conditions. After the R-Studio software analysis, the simple solution and the intermediate solution are obtained. When the condition is both the intermediate solution and the simple solution, it is marked as the core condition, and the remaining intermediate solution is the edge condition.

Table 6. Results of configuration analysis(High-level).

Condition variables	High-level of digital intelligence transformation					
	M1				M2	M3
	H1	H2	H3	H4	H5	H6
IP	⊗	•		⊗	⨂	⨂
TR & DC	●	●	●	●	●	●
KTI	•	⊗			⨂	•
MTP			•		•	⨂
GS			⊗	⊗	⊗	⊗
DIE	●	●	●	●		
Consistency	0.993	0.989	0.995	0.986	0.979	0.977
PRI	0.978	0.96	0.985	0.957	0.934	0.885
Coverage	0.321	0.245	0.322	0.339	0.3	0.27
Unique coverage	0.013	0.003	0.004	0.001	0.014	0.026
BECONS adjusted distance	0.0058	0.0174	0.0116	0.0058	0.0174	0.0087
WICONS adjusted distance	0.0823	0.0877	0.0932	0.0768	0.1371	0.0877
Aggregate consistency	0.979					
Aggregate PRI	0.95					
Aggregate coverage	0.526					

Note: ● and ⨂ represent core presence and absence, respectively; • and ⊗represent marginal presence and absence; Blank space indicates presence or absence(the same below).

In this part, the dynamic QCA method is used to explore the antecedent configuration of the high level of enterprise digital intelligence transformation, and the obtained antecedent configuration is analyzed and named to summarize and refine the configuration path that drives the digital intelligence transformation of automobile manufacturing enterprises. The results of configuration analysis are shown in table 6. A total of 6 configurations can produce a high level of intelligent transformation of automobile manufacturing enterprises. The consistency level of single solution (configuration) and overall solution is higher than the acceptable minimum standard of 0.75, and the coverage of the overall scheme is also higher than the acceptable minimum standard of 0.5. At the same time, the inter-group consistency adjustment distance and intra-group consistency adjustment distance of a single configuration path are both less than 0.2, indicating that the overall path has a high explanatory power, and the generated configuration is a sufficient condition for the high level of enterprise digital intelligence transformation. Further summarizing and refining the configuration of the digital intelligence transformation level of high-level enterprises, the following three configuration modes are obtained.

(1) M1 : digital technology + R & D environment-driven. The model includes configurations H1, H2, H3, and H4.The consistency of the four configurations is greater than 0.98, which can explain 32.1 %, 24.5 %, 32.2 %, and 33.9 % of the sample cases, respectively. In this model, technological R & D capability and digital innovation environment exist as the core conditions of the four configurations, while the marginal conditions have different emphases. Through model analysis, it is found that the strong technological development ability and excellent digital environment of automobile manufacturing enterprises are the key to realize the transformation of digital intelligence. Specifically, the underlying logic of H1, H2 and H3 configurations lies in the positive digital intelligence practice of the enterprise itself and the guidance of the digital innovation environment, while the underlying logic of H4 configuration emphasizes the combined effect of R & D technology and R & D environment.

The typical case of H1 configuration is Huizhou Desay SV Automotive Corporation Limited, which is located in Guangdong Province, which ranks top in intelligent infrastructure. From 2018 to 2022, the financial arrangement of Guangdong Province to support the industrial Internet reached 1.64 billion yuan[31]. With the strong support of local governments, the industrial Internet in Guangdong Province has developed rapidly, and the number of national industrial Internet platforms ranks first in the country. In the excellent digital environment, Huizhou Desay SV Automotive Corporation Limited closely focuses on the blocking points and pain points of the intelligent development of the industrial chain, and focuses on the research and development of core technologies such as intelligent driving, vehicle networking, and intelligent cockpit, and has achieved leading development in the process of scientific and technological research. In addition, it has also actively laid out a comprehensive and perfect product line, intensified efforts to improve intelligent manufacturing and lean production, continuously improved quality control capabilities, and gradually realized the comprehensive cloud of enterprise technology research and development applications. Compared with the emphasis of H1 configuration on technology research and development, H2 and H3 configurations focus more on the intelligent transformation of production process and management mode. The typical case is BYD Company Limited. The company is also located in Guangdong Province, which ranks top in intelligent infrastructure, with excellent digital environment. New energy vehicles are the main direction of the transformation and development of the global automobile industry and an important engine for promoting the sustained growth of the world economy. At the same time, the development of new energy vehicles is one of the important ways to implement the goal of " carbon peak in 2030 and carbon neutrality in 2060 ". As a leading manufacturer of high-end manufacturing in the global new energy automobile industry, BYD Company Limited ' s business covers a wide range and has achieved a complete industrial chain. It not only has a strong scientific and technological innovation ability in automobile material development, automobile product design and development, but also plays an important role in automobile production such as automobile parts and whole machine manufacturing. Its highly vertical integration capabilities not only enable it to establish a leading position in the global new energy vehicle field, but also respond more efficiently to the changing needs of the market and help its future development.

Relatively speaking, the H4 configuration highlights the combined effect of R & D technology and R & D environment. The representative case is SAIC Motor Corporation Limited, which is located in Shanghai, China 's ' international economic center, financial center, trade center, shipping center, science and technology innovation center ' construction site. Under the incomparable excellent environment of ' five centers ', the development strategies of digital economy emerge in an endless stream and most of them are in place, which drives SAIC to implement the national strategy and focus on the upgrading and development of enterprise 's digital intelligence. In terms of digital intelligence technology upgrades, SAIC has not only introduced industry-leading technologies such as double silicon carbide ' quasi-900V ' and high-performance ' super-mixed DMH ', but also realized mass production applications. Its main self-driving car has also obtained the first batch of L3 autonomous driving road test licenses, and declared the Ministry of Industry and Information Technology 's pilot project for access to intelligent connected vehicles. In addition, the full-stack 3.0 electronic architecture, energy closed-loop technology, and central coordinated motion controller (VMC) that it is exploring have also completed phased development work. As a result, SAIC has achieved good results in the construction of new energy industry chain, intelligent vehicle R & D and application, artificial intelligence algorithm and so on, and its own digital intelligence transformation practice is also quite effective.

(2) M2: Digital technology + organization planning driven.The model configuration is H5, configuration consistency is 0.979, coverage is 0.3, which can explain 30 % of the sample cases. Technological R & D capabilities and management transformation planning exist as core conditions, intelligent production and knowledge talent investment are missing as core conditions, and government support is missing as marginal conditions. Through model analysis, it is found that in the case of weak digital foundation in the regional environment, through the enterprise 's active promotion of digital intelligence transformation practice, it can also achieve a higher level of digital intelligence transformation. The representative case is Dongfeng Automobile Corporation Limited. Compared with the developed areas in the eastern coastal areas, the construction of digital infrastructure in Hubei Province is relatively lagging behind, and the level of industrialization is also low. However, with its super concentration on LCV (light commercial vehicle), it has obtained the necessary characteristics of intelligent development : initiative. The Dongfeng Automobile Corporation Limited has long attached importance to technology R & D investment, has independent R & D institutions, and clearly focuses on the development of LCV (light commercial vehicle). By continuously strengthening its investment in product R & D, it has established and improved the market-oriented and business-oriented R & D system. In addition, the company has begun to develop new energy vehicle products since 2005, and is the earliest enterprise in China to engage in new energy demonstration operations and realize the commercialization of new energy. At present, the company 's new energy products cover multiple market segments such as public transportation, highways, and urban logistics.

(3) M3 : Digital technology + high-end talent-driven type. The model configuration is H6, the configuration consistency is 0.977, and the coverage is 0.27, which can explain 27 % of the sample cases. Configuration H6 exists with technology R & D capability and knowledge talent input in the technical dimension as the core conditions, intelligent production and management transformation planning as the core conditions, and government support as the marginal conditions. The analysis of the model shows that in the case of unstable digital environment and insufficient number intelligence practice within the organization, through the strong intelligent technology and stable knowledge talent input of the enterprise, we can focus on solving the key technology ' neck ' problem in the transformation of number intelligence, and can also achieve a higher level of number intelligence transformation. The representative case is Weichai Power Corporation Limited. Compared with the developed eastern coastal areas, the construction of digital infrastructure in Shandong Province is also lagging behind, but the business focus of Weichai Power is on the internal combustion engine and power system, which forms the unique advantages of Weichai Power itself. The Weichai Power Corporation Limited has built a lot of innovation platforms, not only the only key laboratory of internal combustion engine and power system in China and the national fuel cell technology

innovation center, but also the ' Eight Institutes and One Center ' Weichai Power Central Research Institute ; in addition, it has also established ten cutting-edge technology innovation centers around the world, with world-class universities, scientific research institutions, multinational companies ' chain innovation ', global collaborative research and development, seamless connection. In a word, the Weichai Power Corporation Limited firmly grasps the key variable of knowledge talents and devotes itself to grinding new technology, which not only provides a solid guarantee for its casting of the most quality and competitive products, but also provides the core ability for its digital intelligence transformation.

Further analysis of the configuration of the digital intelligence transformation level of high-level enterprises shows that there is an overlapping relationship between the antecedent conditions of some configurations. In the three modes of high enterprise digital intelligence transformation level configuration, technology R & D capability and digital innovation environment constitute the overlapping conditions of H1-H4 path, among which technology R & D capability constitutes all the overlapping conditions of H1-H6 path. It can be seen from this analysis that, on the one hand, technology R & D capabilities play a stable and universal role in the process of enterprise digital intelligence transformation ; on the other hand, the digital innovation environment is also a very important factor for the transformation of enterprises. In addition, the results of realizing the high level of enterprise 's digital intelligence transformation have different configuration modes, which indicates that enterprises can use other antecedent conditions to replace them, so as to achieve the effect of ' the same way ' of digital intelligence transformation.

3.2.2. Between Results

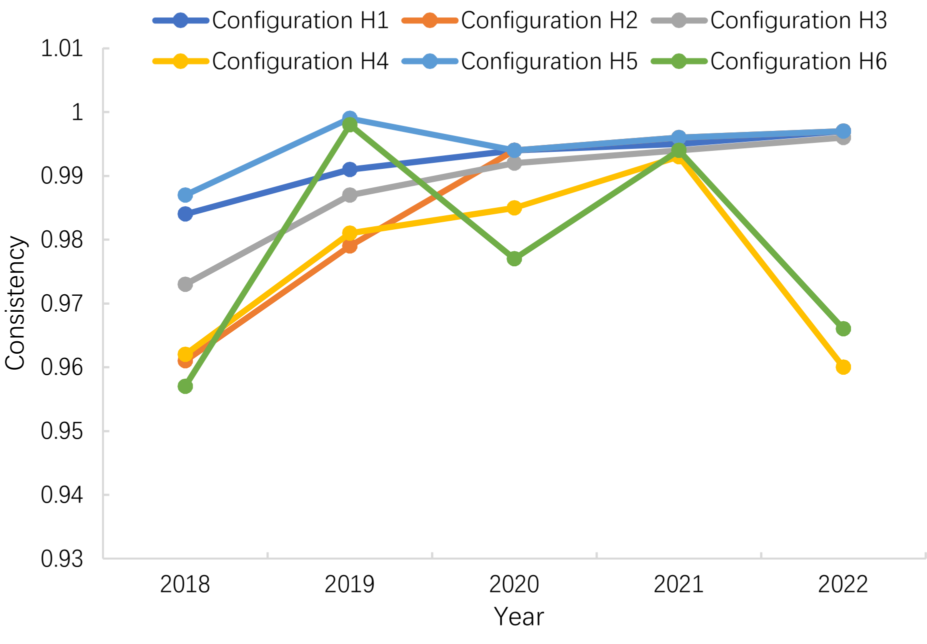

Figure 2. Consistency change between groups

In order to deal with the problem of time blind area in traditional QCA configuration, the configuration time effect is discussed here with the help of group consistency. As shown in Figure 1, the inter-group consistency of the generated six configurations is greater than 0.95, which is greater than the consistency criterion of 0.75 ; at the same time, the consistency adjustment distance between groups is calculated, and the results are less than 0.2, indicating that there is no obvious time effect in the above configuration. Further research on each configuration change found that the consistency level of all configurations fluctuated between 0.95 and 1.00 from 2018 to 2022, and generally showed an upward trend. On the one hand, the results of the inter-group analysis make up for the deficiency of the consistent change trend that the previous cross-section configuration cannot reflect in the vertical axis of time. On the other hand, it shows that the six configurations have a good explanatory power between 2018 and 2022. The fluctuations of these six configurations in 2018-2022 indicate to a certain extent that the driving paths in different periods will show energized turbulence. It is worth noting that the consistency change trend of configuration H1, configuration H2 and configuration H3 has less influence and slower speed, which indicates that when the digital innovation environment is the precondition and the technology research and development ability is the core condition, it has a more stable driving effect.

3.2.3. Robustness Analysis

In this paper, the robustness test is carried out on the configuration of automobile manufacturing enterprises to produce high level of intelligent transformation. Among them, drawing on the practice of Du Yunzhou [27], the configuration robustness test is carried out from the adjustment of the number of case thresholds and the adjustment of the consistency threshold. Firstly, the case frequency threshold is adjusted from 1 to 2 ; secondly, the PRI consistency threshold is adjusted from 0.75 to 0.8. The results show that the overall consistency of the digital intelligence transformation level of high-level enterprises has changed from 0.979 to 0.978 and 0.979 respectively, and the configuration has not changed significantly. Therefore, according to the relevant evaluation criteria, the above research conclusions are considered to be robust.

4. SUMMARY

4.1. Summary

The main conclusions of this paper are as follows :

(1) From the perspective of necessary conditions, there is a complex causal relationship in the digital intelligence transformation of automobile manufacturing enterprises. Any single antecedent condition cannot alone constitute a necessary condition to drive the digital intelligence transformation of automobile manufacturing enterprises.

(2) From the perspective of the configuration of digital intelligence transformation level of high-level enterprises, the antecedent conditions of technology, organization and environment dimensions are 'multiple concurrency ', forming three types of paths : digital technology + R & D environment-driven, digital technology + organizational planning-driven and digital technology + high-end talent-driven. There is a configuration full overlap relationship between the antecedent condition technology R & D capability, and there is an overlap relationship between the technology R & D capability and the digital innovation environment.

(3) From the perspective of the configuration of non-high-level enterprises ' digital intelligence transformation level, the antecedents of technological R & D capabilities in the technical dimension are the core reasons for the failure of the digital intelligence transformation of the automobile manufacturing industry, and the digital innovation environment in the environmental dimension is an important reason for the failure of the digital intelligence transformation of the automobile manufacturing industry.

4.2. Practical Enlightenment

(1) Give full play to the subjective initiative, strengthen the application of configuration coordination thinking. According to the above, different configuration modes show that the intelligent transformation of automobile manufacturing enterprises has the characteristics of high complexity, and any single antecedent condition cannot drive the automobile manufacturing enterprises to realize the intelligent transformation alone. Therefore, the formulation of enterprise development policies needs to integrate and optimize the digital ecosystem from the perspective of configuration, jump out of the limitations of single conditions, coordinate the antecedent conditions of each dimension, and promote the digital transformation of automobile manufacturing enterprises.

(2) Enterprises pay close attention to technology research and development, and constantly strengthen innovation investment. Automobile manufacturing enterprises need to clarify that technology research and development is the core element of enterprise digital intelligence transformation, and excellent digital innovation environment is an important factor in the transformation path. According to the three types of paths of high-level enterprise digital intelligence transformation, automobile manufacturing enterprises should focus on their own technology research and development capabilities, rely on the support of local governments and the excellent digital innovation environment in their locations, and jointly play the important role of technology research and development and digital environment, and constantly develop in the direction of high-quality digital intelligence.

(3) The government helps optimize the digital environment, and enterprises implement policies according to local conditions to explore future development. The successful transformation of enterprises into digital intelligence requires external efforts from the government. First of all, local governments should increase the investment and construction of digital infrastructure, especially digital technology trading markets, and continuously improve the digital environment in the region. Secondly, relevant government departments should also formulate and introduce corresponding financial subsidies and tax incentives to create a good external institutional environment for the innovation and application of enterprise technology. Finally, for enterprises with effective transformation, the government should actively show its development results and encourage enterprises to further develop in the transformation of digital intelligence, so as to fully show the role of ' leading geese ' and significantly enhance the vitality of ' geese '.

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