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On the Digital Transformation of the Automobile Manufacturing Industry in the Chengdu-Chongqing Economic Circle: Mechanism of Action and Feasible Paths

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Abstract: With a long industrial chain and a powerful ability to drive other industries, the automobile manufacturing industry has a prominent strategic position in the national economy. In recent years, many countries have put on their agenda the digitalization of the automobile manufacturing industry, leading to an connected, autonomous, shared, and electric (also known as CASE)^① development trend in the industry. As one of the six major automobile industry clusters in China, the Chengdu-Chongqing economic circle has achieved initial results in the digital transformation of the automobile manufacturing industry. However, the region is still faced with some constraints, such as insufficient digital infrastructure, relatively slow development of new automobile products, insufficient innovation ability of the automobile industry, and complex digital transformation of small and medium-sized automobile enterprises (automobile SMEs). This paper intends to construct a framework for the mechanism of action of the digital transformation in the automobile manufacturing industry, analyze the effects of the digital transformation of the automobile manufacturing industry in the Chengdu-Chongqing economic circle, and propose feasible paths for the digital transformation of the automobile manufacturing industry in the region by drawing on domestic and international experience in this regard. The specific paths include: (a) Smoothing the “dual-core” data chain to facilitate the digital transformation of the automobile manufacturing industry; (b) Developing the new energy vehicle (NEV) industry to upgrade the quality of automobile products; (c) Achieving corner overtaking in the digital transformation of the automobile manufacturing industry with digital technology; (d) Jointly building the automobile industrial park to promote the digital transformation of the industry; (e) Addressing problems facing automobile SMEs in digital transformation via targeted policy tools.

Keywords: Chengdu-Chongqing economic circle, automobile manufacturing industry, digital transformation, mechanism of action

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① CASE refers to the connected, autonomous, shared, and electric development of the automobile industry.

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The manufacturing sector is a major part of the real economy. It is also the foundation for a country to stand firm, a driving force for a nation to thrive, and an important pillar to consolidate the foundation of a country. China has formed a modern industrial system with large-scale, full-range categories and well-established facilities (Kong & Ding, 2021). With the rapid development of 5G, big data, artificial intelligence, and other next-generation digital technologies, digitalization is playing an increasingly prominent role in economic and social development, and countries around the world have put on their agenda the digital transformation of their manufacturing industries. Under this circumstance, promoting the digital transformation of the automobile manufacturing industry has become an inevitable choice for our country to foster the high-quality development of its manufacturing sector under the new development pattern.

The Chengdu-Chongqing economic circle has nurtured well-known automobile enterprises such as Changan Auto, Geely, Volvo, and Volkswagen, as well as several core parts manufacturing enterprises engaging in the manufacturing of drive motors, electronic controls, and transmissions as well as high-voltage power distribution units (PDU), on-board chargers (OBC), and direct current (DC) converters such as BYD Battery, CATL, and Continental Huayu Brake Systems (Chongqing). The region has formed a relatively complete NEV industrial chain and is striving to build a trillion-level automobile industry cluster by continuously smoothing the information chain, improving the industrial chain, integrating the innovation chain, sharing the supply chain, and integrating the value chain of the automobile manufacturing industry. In October 2021, the CPC Central Committee and the State Council issued the *Master Plan for the Construction of the Chengdu-Chongqing Economic Circle (Master Plan)*, proposing to build twin engines for the high-quality development of China's manufacturing sector, vigorously promote the integrated development of information technology and the real economy, accelerate industrial digitization, focus on the intelligent connected vehicles (ICVs) and NEVs, and build a high-level R&D and production base for the automobile industry, which charts a clear course for the transformation and upgrading of the manufacturing industry in the Chengdu-Chongqing economic circle. Therefore, how to accelerating the digital transformation of the automobile manufacturing industry has become an important topic that is urgently needed for the construction of the Chengdu-Chongqing economic circle.

Literature Review and Summary

Scholars proposed to promote the digital transformation of the manufacturing sector and have made rich research achievements in terms of becoming the driving force behind the positive impacts of digital transformations on core enterprises. Matt (2015) and Vogelsang (2018) held that technological innovations, organizational structures, and cultural environments are the three driving forces for the digital transformation of manufacturing enterprises, of which, technological innovations will bring about changes in the market and then affect the organizational structures,

enterprise strategies, and cultural environments, thus producing a positive impact on enterprise innovation performance and resource management. Foreign scholars mainly focus on the following aspects in terms of the research on the digital transformation of the automobile manufacturing industry: (a) Paths for the digital transformation of automobile manufacturing enterprises. Kessler & Christoph (2017), and Candelo & Elena (2019; 2018) argued that the digital transformation of automobile manufacturing enterprises covers three dimensions, that is, the digitalization of the value chain, products and services, and business models. (b) Technologies needed for the digital transformation of the automobile manufacturing industry and their application. Svahn & Henfridsson (2012) and Gerhard Knolmayer et al. (2002) found that the application of digital technologies such as integrated data analysis systems and SAP supply chain management systems in the automobile manufacturing industry can shorten the life cycle chain of products and improve product quality while reducing enterprise cost and improving efficiency, thus helping enterprises to maintain competitive advantages. The application of the Agent technology, PiWeb production management system, MidSphere cloud platform, and other digital technologies in automobile manufacturing enterprises such as Mercedes-Benz and Volkswagen indicate that these technologies play a very important role in providing automobile manufacturing enterprises with digital transformation solutions and technical support, and promoting the digitalization of automobile production processes.

With the rapid development of the digital economy, Chinese scholars are also gradually deepening their research on the digital transformation of the manufacturing sector and have made considerable achievements in the following aspects: (a) Paths for the digital transformation of the automobile manufacturing industry. Citing FAW Group and Geely Automobile as examples, scholars analyzed the effect and problems of their digital transformation and put forward paths for their transformation on the basis of organizational management, digital technology innovation, and other perspectives (Shen, 2020; Lv, 2021; Gao, 2021). (b) The role of digital transformation in the automobile manufacturing industry. Ma Jian and Dong Hongpeng (2021) found that during the R&D of automobiles, the digitalized lean management of automotive development projects can effectively improve the efficiency of project management and reduce internal transaction costs. Zhong Xiangping (2020) held that the digitalization of automobile sales and after-sales business promotes the formation of data links among subsystems of automobile products and feeds back the R&D and production links of automobiles, thus realizing large-scale customization and improvements in product quality. (c) Performance evaluation of the digital transformation of the automobile manufacturing industry. A study by Yi Luxia et al. (2021) found that the intensity of digital transformation is positively correlated with the main business performance of enterprises and has a more significant driving effect on state-owned enterprises and practical enterprises based on the data of A-share listed enterprises in Shanghai and Shenzhen. Wang Heyong and He Hongman (2022) constructed an evaluation system for the digital transformation of the manufacturing sector and evaluated the digital transformation practices of 64 Chinese automobile

manufacturing enterprises using the entropy weights method of CRITIC. The study found that Chinese automobile manufacturing enterprises see sound momentum in the digital transformation and that it will improve enterprise performance by reducing the operating cost rate, administrative expense rate, and sales expense rate.

The existing literature not only deeply analyzed the influencing factors, roles, and paths for the digital transformation of the automobile manufacturing industry from a theoretical perspective but also explored the technology applications in the digital transformation of the manufacturing industry and evaluated its effects by adopting empirical methods, thus laying a foundation for the in-depth research in this regard. However, there are some shortcomings in the existing research. First, there are more studies on the digital transformation of the whole manufacturing sector but fewer on the digital transformation of a specific industry. Second, most of the research on the digital transformation of the automobile manufacturing industry focuses on the practice and development status and trends of enterprises in digital transformations, while little research has been done on its mechanism, law of development, and path selection. Third, little research has been done on the digital transformation of the automobile manufacturing industry in a certain region. At present, the research on the digital transformation of the automobile manufacturing industry mainly discusses the overall situation in the whole country, and little exploration has been made into the situation of a specific region. Most of the research is on the digital transformation of the automobile manufacturing industry in the eastern regions, such as the Yangtze River Delta and the Pearl River Delta regions, while little can be found on that in the western region.

The Chengdu-Chongqing economic circle occupies a unique and important strategic position in the overall development of China. As one of the pillar industries of the Chengdu-Chongqing economic circle, the digital transformation of the automobile manufacturing industry is a realistic requirement for the high-quality development of the automobile manufacturing industry. In view of this, by taking the automobile manufacturing industry in the Chengdu-Chongqing economic circle in western China as its research object, we examined the mechanism of action of the digital transformation in promoting the transformation and upgrading of the automobile manufacturing industry, objectively evaluated the effects of the digital transformation of the automobile manufacturing industry in the Chengdu-Chongqing economic circle, and explored paths for the digital transformation of the automobile manufacturing industry. Our goal is to provide theoretical enlightenment and practical references for promoting the high-quality development of the automobile manufacturing industry in the Chengdu-Chongqing economic circle.

Mechanisms of Actions of the Digital Transformation of the Automobile Manufacturing Industry

Data and digital technology are the two key elements constituting the digital economy, and industrial digitalization is a major development path of the digital economy. These three factors

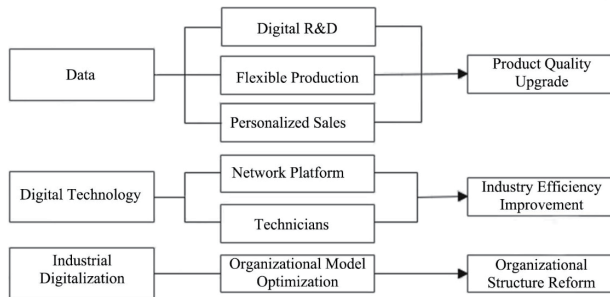


Figure 1 Mechanisms of Actions of the Digital Transformation of the Automobile Manufacturing Industry

jointly promote the digital transformation of the automobile manufacturing industry, with data enabling the upgrading of product quality, digital technology improving efficiency, and industrial digitalization optimizing the organization modes of enterprises (as shown in Figure 1).

Data Enables the Quality Upgrading of Automobile Products

Data, as an emerging factor featuring low marginal cost, little loss, and convenience for replication and sharing, has become a key production factor and an engine for deepening the digital economy. China still needs to further improve its independent innovation capability in the manufacturing sector, especially in the traditional manufacturing sector, which features decentralization in product design and R&D and low collaboration (Wang & Chen, 2022). Compared to the United States, Germany, and other developed countries, most of the Chinese manufacturing enterprises reside in the processing and assembly link of the industrial chain, leading to the low technical content and added value of their products. Data runs through the whole life cycle of the automobile manufacturing industry and plays an increasingly important role in the R&D, production, circulation, distribution, and consumption of automobile products. It is the basis of the digital transformation of the automobile manufacturing industry. With the continuous progress made in data mining, processing, algorithm, and other technologies, data is gradually integrated into the production process to constantly improve product quality. Data can build a digital platform between manufacturing enterprises and consumers, provides enterprises with digital production workshops, customizes digital sales plans for consumers, and realizes precise matching plans for customized production. In this way, it can avoid information asymmetry between manufacturers and consumers, improve the qualification rate and satisfaction degree of products, expand effective supply, and constantly promote the upgrading and iteration of products.

Data can enable the digital transformation of the automobile manufacturing industry and promote the quality upgrade of automobile products, which is embodied in the following aspects.

First, it concerns the R&D of automobile products. (a) Auto manufacturing enterprises jointly build a collaborative platform for product R&D to break temporal and spatial constraints and realize the sharing of data generated in historical model production and design among a variety of origins. With this platform, enterprises can effectively use global resources to improve their independent R&D capacity, constantly elevate the R&D efficiency of NEVs and ICVs, and provide high-quality automobile product solutions for consumers. It will also help the automobile manufacturing industry extend to the back end of the industrial chain and the high end of the

value chain. (b) Auto manufacturing enterprises jointly build and share a big data platform to break the information barrier between the R&D of automobile manufacturing enterprises and the needs of consumers. Via this platform, consumers can timely respond with their use statistics and improvement suggestions to automobile enterprises, while automobile enterprises can use the platform to collect massive amounts of information, capture the needs of consumers in real time, and carry out accurate, customized design and production by using consumers' personalized data, thus shortening the R&D cycle and lowering the product cost to avoid homogeneous automobile products.

Second, it involves the flexible production of products. (a) The automobile industry features a long industrial chain, and automobile manufacturing enterprises need to purchase a variety of automobile parts. The purchasing departments can realize accurate judgment and prediction of the information related to auto parts to be purchased and accurate matching of enterprises engaging in the manufacturing of such parts through data perception, collection, transmission, storage, calculation, analysis, and application to formulate more efficient purchasing plans. (b) Auto production covers various links such as stamping, welding, assembly, and coating. The traditional automobile production line requires a large amount of labor, with poor production efficiency and low controllability of product quality. The digital workshop can give full play to the value of data, collect data from the production line and conduct real-time monitoring of such data through digital, information, and intelligent means. It can accurately and efficiently manage and control the production materials, equipment, and processes of products, thus reducing resource waste and human operational errors, thus shortening the production cycle of products, and improving the qualification rate of products.

Finally, it is also embodied in the personalized sales of products. Due to the single sales model, it is hard for the traditional sales departments of the automobile industry to quickly collect information and timely feed it back to the sales link. In the era of the digital economy, automobile enterprises can pay more attention to satisfying the personalized needs of consumers, enhancing their experiences, and tapping potential profits. Data can continuously promote the integrated development of the automobile industry and the service industry and provide automobile enterprises with sales and service tools to directly access customers and give birth to a variety of new sales and service models with the help of big data technology. For example, it can pool current and potential information about consumers' needs through online and offline marketing scenarios to help enterprises make personalized sales plans. It can provide consumers with one-to-one services throughout the pre-sale, sale, and after-sales process to achieve the precise matching between the products and customers' needs via big data technology. In the product delivery link, it can use big data to help enterprises select the optimal storage mode, logistics route, and delivery method. In the after-sales service link, it can provide consumers with consumer-centered butler services during the whole life cycle of their vehicles to enhance their perception of consumers and increase their stickiness (Bai & Ren, 2021).

Digital Technology Improves the Efficiency of the Automobile Manufacturing Industry

As a kind of technology developed with the advent of computers, digital technology includes various modules such as blockchain, big data, cloud computing, and artificial intelligence. Featuring fast iteration, rapid diffusion, and strong permeability, it is the foundation for the development of the digital economy. The industrial chain of the traditional manufacturing industry features a simple linear structure, under which the division of labor depends on the information feedback of its adjacent organizational departments, and the spatial distribution of the industrial chain is subject to geographical constraints (Li, Li & Zhou, 2020). Therefore, it is necessary to integrate digital technology with traditional production factors and optimize the allocation of traditional production factors through algorithms to improve the marginal productivity of production factors, including material capital, human capital, land, and technology. At the same time, with the application of the next-generation digital technology, a new infrastructure featuring the industrial Internet has been formed, which can realize all-round connectivity across equipment, systems, factories, and regions. It will promote the dynamic evolution of the industrial chain into a complex network system and accelerate the collaborative development of the manufacturing sector and the total factor productivity of the sector. Human capital is the key to improving the efficiency of the manufacturing sector. Although digital transformation has, to some extent, replaced the low-skilled labor force in the manufacturing sector, it also puts forward higher skill requirements for practitioners through the “enhancement effect” (Hui & Yang, 2022). Digital technologies such as artificial intelligence and intelligent mobile terminals provide practitioners with a more convenient learning platform, while other technologies such as online education and training and artificial intelligence simulation offer a wider range of channels for workers to learn new knowledge. Abundant learning resources and convenient learning methods will optimize the employment structure of the sector.

Data technology can make possible the digital transformation of the automobile manufacturing industry and improve the efficiency of the industry, which is embodied in the following aspects.

First, the automobile industry spans widely in the horizontal dimension, which highlights the importance of collaboration between automobile manufacturers and suppliers. With the emergence of digital technologies such as an integrated Internet, blockchain, industrial Internet, virtual reality, and their wide applications in the automobile manufacturing industry, a digital ecosystem featuring connectivity between digital space and the physical world has been created. In this ecosystem, shackles that hinder information transmission among the main bodies of the division of labor in the automobile manufacturing industry and geographic constraints have been broken, creating a seamless application scene between humans and machines in which efficient collaboration between humans and machines can be achieved. It can realize the comprehensive perception, dynamic transmission, and real-time analysis of the data in the automobile intelligent manufacturing production line and reinforce the close connection of the online and offline

internet-wide, full-range, and all-channel supply chain system, including the logistics, information flow and capital flow of the industry. It can promote the open sharing of business data among customers, automobile enterprises, and parts suppliers, enhance the integration ability of upstream and downstream resources and data of the automobile industry chain, and reduce the transaction costs of the whole industrial chain, thus further improving the production efficiency and total factor productivity of enterprises (Li & Han, 2021).

Second, automobile manufacturing is a complex process, each link of which requires professional, refined, specialized, and novel manufacturing technologies. At present, the independent innovation capability of the Chinese automobile manufacturing industry still has room to improve. In the era of the digital economy, the independent innovation capability of the automobile industry has been greatly enhanced with the increased input of innovation resources and training of compound innovative talents, and innovations in automobile manufacturing products, models, and business forms based on digital technology have emerged one after another. Breakthroughs have been made in core technologies such as batteries, motors, electric controls, environmental perception, wireless communication, and intelligent connectivity of NEVs and ICVs. With the rapid development of innovative technologies such as the all-round network link, sensing technology, and intelligent information processing technology of the Internet of vehicles (IoVs), the automobile industry has seen constant improvements in technical levels and optimal spillover effects of technology and knowledge, which has promoted the efficiency of resource allocations and innovations in the automobile manufacturing industry and enhanced the overall efficiency of the industry.

Industrial Digitalization Promotes the Optimization of the Organizational Mode of the Automobile Manufacturing Enterprises

Industrial digitalization is to promote the digital transformation of traditional enterprises and key industries and realize the digital transformation and upgrading of the manufacturing sector. Under the wave of the digital economy, it is crucial for automobile enterprises to establish an organizational structure that matches their digital transformation (Han, 2020). The previous isolated and closed organizational mode that highlights internal organizational efficiency and pursues wide-scale and high-speed development is no longer suitable for the current market environment. The automobile manufacturing industry is faced with huge changes in organizational management modes and business models. In order for the industry to stand firm in the digital economy, it is the optimal choice to carry out enterprise digital transformation, and industrial digitalization is the main driving force to promote the transformation. Digital transformation involves not only the transformation of technology but also that of our thinking mode. The key to successful digital transformation lies in the transformation and restructuring of the consumer-centered business process of automobile enterprises rather than the transformation of technology. The rapid development of industrial digitalization is driving

the managers of automobile enterprises to develop strategic and data-based thinking modes to respond to digital transformation, conceive an overall vision of automobile enterprises' digital transformation from a strategic perspective, design the top-level architecture on this basis, and focus on digital management decision-making. By innovating the cognition of managers, we can promote the internal and external collaboration of the organizational mode, facilitate the flexibility, innovativeness, and network-oriented development of multi-agent collaboration among different fields, and push forward the consumer-centered flat management mode to improve the organizational management efficiency and production efficiency of manufacturing enterprises and drive the digital transformation of the automobile manufacturing industry.

Industrial digitalization enables the digital transformation of the automobile manufacturing industry and promotes the optimization of the enterprise organizational mode, which is mainly embodied in the following aspects.

First, it can optimize the organizational structure of enterprises. The traditional and closed organizational structure of automobile enterprises not only limits the self-development of employees but also leads to poor coordination among various departments and low work efficiency. However, based on data and technology, automobile enterprises can internally build a borderless organization oriented to stimulate people's creativity and set up a small group organizational mode distinguished through cross-functional collaboration by connecting various functional departments, unifying data standards, reducing non-value creation activities, and streamlining business processes (Li, Qiu & Cheng, 2018), thus enhancing employees' work efficiency and teamwork cooperation. Externally, they can reinforce the linked industrial chains of the automobile manufacturing enterprises, strengthen communications with ecological partners, complement each other in different links of production and circulation, and promote a wider and deeper market division of labor, thus realizing efficient collaboration across fields and regions, all while keeping abreast with and satisfying the market demands (Zhu, 2022).

Second, it can optimize the organization and management mode of enterprises. Automobile manufacturing enterprises are large in scale. The traditional management mode generates multiple management levels, and the decisions made by the top levels are often ill-grounded and lag behind market changes leading to resource waste and low management efficiency. With the help of information technology, various functional departments within automobile enterprises are connected to improve the speed of data flow, reduce communication barriers among different levels, and lower information asymmetry. On the one hand, it can transfer and share information in a faster, more accurate, and more timely manner and reduce communication costs within enterprises; on the other hand, it can achieve the linkage among procurement, production, sales, and after-sales departments, predict the future development trend of the industry by using big data analysis technologies and other technologies, and make quick and flexible responses to market changes, thus improving the management efficiency of enterprises (Zhang & Fu, 2021).

Analysis of the Effect of Digital Transformation on the Automobile Manufacturing Industry in the Chengdu-Chongqing Economic Circle

The Chengdu-Chongqing economic circle comprises 27 districts (counties) in downtown Chongqing including Wanzhou and Fuling, as well as parts of Kaizhou and Yunyang, and 15 cities, including Chengdu, Zigong, and Deyang in Sichuan province. After years of exploration and practice, the region has made initial achievements in the digital transformation of the automobile manufacturing industry but is still faced with various constraints.

Practical Exploration and Initial Achievements

In recent years, the Chengdu-Chongqing economic circle has grasped the opportunities of the national strategy of building digital economy innovation and development pilot zones to promote the digital development of the automobile manufacturing industry and has made initial achievements in the digital transformation of the automobile manufacturing industry.

Gearing up for the Digital Transformation of the Automobile Manufacturing Industry with Top-level Design

In their outlines of the 14th five-year plans, cities or districts (counties) in the Chengdu-Chongqing economic circle all proposed to promote the deep integration of the digital economy and the real economy and vigorously develop NEV and ICV industries by seizing the opportunities for building the Chengdu-Chongqing economic circle to build an advanced industrial cluster of the automobile manufacturing industry in the region and promote its high-quality development. The *Master Plan* further clarifies the development orientation and key tasks of the automobile manufacturing industry in the Chengdu-Chongqing economic circle. Against this backdrop, the *Strategic Cooperation Agreement on Co-building a World-Class Advanced Automobile Industrial Cluster* and the *Implementation Plan for the High-quality and Coordinated Development of the Auto Industry in the Chengdu-Chongqing economic circle* have been signed successively. It is planned that by 2025, the automobile output of Chengdu and Chongqing will strive to exceed 3 million units, with the industrial output value totaling over RMB 600 billion.^① The top-level design has clarified the direction for the digital transformation of the automobile manufacturing industry in the region. Guided by the *Master Plan*, the two places have made practical exploration and bold attempts at the digital transformation of the automobile manufacturing industry, effectively promoting the digital transformation process of the industry.

① Cheng, Y. X. New landscapes of industrial collaboration: Chengdu and Chongqing jointly build a high-level automobile industry R&D, production and manufacturing base. Retrieved from <http://sc.people.com.cn/n2/2021/1023/c345167-34970295.html>.

Consolidating the Foundation of Digital Transformation of the Automobile Manufacturing Industry with New Infrastructure

The Chengdu-Chongqing economic circle is accelerating the layout of new infrastructures, such as automotive industrial Internet and NEV charging piles, laying a foundation for the digital transformation of the automobile manufacturing industry.

Building New Infrastructures to Promote the Application of NEVs. NEVs represent the mainstream trend of the future automobile industry, and charging piles are the basic guarantee for their promotion and application. As of 2021, about 119,000 public charging piles for NEVs had been set up in the Chengdu-Chongqing economic circle, of which 61,000 are in Chengdu and 50,000 are in Chongqing, far more than in other cities.^① The construction of NEV charging piles has driven the fast development of the NEV industry and has become an important guarantee to facilitate the digital transformation of the automobile manufacturing industry and improve the quality of automobile products in the region.

Building an Internet Platform for Automobile Manufacturing to Enhance the Efficiency of the Automobile Manufacturing Industry. The automobile manufacturing industrial Internet is an integrated system based on advanced digital technologies, which connects the whole system, industrial chain, and value chain of the automobile industry, providing support for the digital transformation of the automobile manufacturing industry. The Geega Industrial Internet Platform (Geega Platform), independently developed by Guangyu Mingdao Digital Technology Co., Ltd. in Chongqing, a company owned by Zhejiang Geely Holding Group, is the only cross-industry and cross-field industrial Internet platform in China with a background in the automobile manufacturing industry, which has created favorable conditions for the digital transformation of the automobile manufacturing industry in the Chengdu-Chongqing economic circle. With the help of the Geega Platform, more than 200 automatic transport vehicles in Chengdu Lynk & Co have accurately and efficiently completed the transportation of various automobile parts, which improves the logistics and storage efficiency of the production workshop and reduces labor costs by 8%. Nearly 3,000 welding spots are connected to a network on the quality management system to monitor the production process and detect defects in the welding spots in real time, increasing the qualification rate by 8%,^② helping Chengdu Lynk & Co to be listed in the 2021 Industrial Internet Platform Pilot Projects initiated by the Ministry of Industry and Information Technology. At the same time, Geely has developed dozens of industrial apps, including Real-time Analysis of Screwing Robot and Size Butler by analyzing the production process data collected through the Geega Platform, providing a referential solution to the digital transformation of the automobile

① The data is summarized according to relevant information on the Internet. As it is hard to access the data in the entire region of the Chengdu-Chongqing Economic Circle, the data of 21 districts in downtown Chongqing and 28 districts (cities) in Chengdu, Mianyang, Deyang, Nanchong, Meishan, Suining, and Dazhou were selected to reflect the distribution of NEV charging piles in the region.

② Geega industrial internet platform: Extending the automobile industry chain and creating a cross-industry and cross-field service ecosystem. Retrieved from <https://baijiahao.baidu.com/s?id=1728789270194762734&wfr=spider&for=pc>.

manufacturing enterprises in the Chengdu-Chongqing economic circle and beyond, and greatly improving the production efficiency of the automobile manufacturing industry.

Enhancing the Efficiency of the Automobile Manufacturing Industry with Independent Innovation Capability

The Chengdu-Chongqing economic circle is stepping up innovation and breakthroughs of digital technology to improve the R&D and production efficiency of the automobile industry, injecting strong innovation impetus for the digital transformation of the automobile manufacturing industry. The region is stepping up efforts to build a national IoV pilot zone in Liangjiang New Area, which is the fourth in China and the first in western China of this kind, to expand Changan Auto's leading edge in the massive production technology of the autonomous driving field. It is actively laying out the ICV industry and promoting the Chengdu Sino-German ICV to integrate the ICV resources in Chengdu and Chongqing fully.. Efforts have also been made to accelerate the integration of support policies for NEVs and attract CATL and SVOLT, two giants in the NEV battery industry, to settle in Yibin and Dazhou. At present, the Chengdu-Chongqing economic circle continues to keep abreast with the cutting-edge technologies in the automobile industry and has supported the launch and operation of 440 hydrogen fuel cell vehicles,^① striving to create a national demonstration city cluster of hydrogen fuel cell vehicles, and jointly building a hydrogen fuel cell corridor in the Chengdu-Chongqing economic circle. At the same time, the region pays much attention to talent cultivation and introduction. There are about ten auto-related professional colleges and universities in Chengdu and Chongqing. Chongqing University ranks high in universities and colleges of this kind in China and is an important training base for automobile talent in Southwest China. The two places emphasize the joint introduction and cultivation of talent. The specific measures include encouraging University of Electronic Science and Technology of China and Chongqing University to establish industrial alliances with renowned automobile enterprises such as Changan Auto and FAW-Volkswagen, promoting R&D talent in enterprises to continue their studies in universities, and attracting outstanding talent from universities to engage in the R&D of automobile enterprises. These measures have provided talent support for the digital transformation of the automobile manufacturing industry.

Improving the Supporting Facilities for the Automobile Industry with the Application of the Big Data Platform

According to rough statistics, there are a total of 210 automobile parts enterprises in the Chengdu-Chongqing economic circle, of which there are 130 enterprises in Chengdu and Chongqing that provide supporting services for complete vehicle manufacturers involving

① Liangjiang Observation: How do these major projects drive the Chengdu-Chongqing economic circle? Retrieved from <https://baijiahao.baidu.com/s?id=1736943637850096567&wfr=spider&for=pc>.

power systems, interior and exterior decoration, chassis, and other fields.^① In 2020, the two places launched a supply and demand information platform for the automobile industry chain, via which complete vehicle manufacturers can release their requirements for automobile parts. Parts suppliers can upload their corporate information and product details, quickly realizing the matching of supply and demand information. The establishment and operation of the platform have further improved the integration and coordination of the automobile industry in the Chengdu-Chongqing region. In 2021, the number of enterprise users of this platform soared to 3,370 in Sichuan and Chongqing, allowing the matching rate to exceed 70% in the region.^② As of May 2022, the platform had attracted more than 3,500 complete vehicle manufacturers and parts suppliers, with a total purchase amount of more than RMB 10 billion,^③ greatly improving the production efficiency of the automobile industry.

Development Weaknesses and Constraints

Although the region has made certain progress in the digital transformation of the automobile manufacturing industry, there are still some factors restricting its further development.

Insufficient Coverage of New Digital Infrastructure Hardly Meets the Upgrading Demand of the Automobile Manufacturing Industry

The development of NEV charging piles is highly dependent on infrastructures related to new technologies and communication networks. However, insufficient coverage of charging piles and inadequate performance in product R&D and innovation in this regard make it difficult for the Chengdu-Chongqing economic circle to meet the vibrant demand for the development of NEVs. The region is still faced with various problems in the application of charging piles, such as difficulty in operation and management, poor front-end user experience, and lack of convenience, which has restricted the transformation and upgrading of the automobile manufacturing industry in the region. According to the lists of the “TOP 50 Industrial Internet Solution Providers of 2021” and “Top 30 Industrial Internet Platforms in 2021”, among the automobile enterprises that have undergone digital transformation, CMM based in Chongqing is the only industrial Internet enterprise in Chongqing and Sichuan, while the numbers in the Yangtze River Delta and Pearl River Delta regions are five and seven respectively.^{④⑤} In the Chengdu-Chongqing

① Zhong, Q. N. 130 auto parts enterprises partner with complete vehicle enterprises. In the H1 of 2022, the construction of the Chengdu-Chongqing economic circle was accelerated through "dual-core" linkage. Retrieved from <https://baijiahao.baidu.com/s?id=1738761664448782889&wfr=spider&for=pc>.

② Industrial collaboration yields fruitful results: Sichuan and Chongqing will work together to build the third trillion-level industrial cluster. Retrieved from <https://baijiahao.baidu.com/s?id=1720982903493968790&wfr=spider&for=pc>.

③ Challenges and new policies of the world-class trillion-level automobile industry cluster in the Chengdu-Chongqing economic circle under the background of maintaining economic stability. Retrieved from https://mp.weixin.qq.com/s/?__biz=MzIzNzQxMjg5NQ==&mid=2247491616&idx=1&sn=57381a20191555f3d6c7e8c8b9f84a4&chksm=e8eba880dfbc2196d3d69cca280208b2f1830611fef16406a4fd887106ae647dd2a2ce357ed&scene=27.

④ What should we learn from the Industrial Internet Top 50 List? Retrieved from https://www.sohu.com/a/502121551_100210081.

⑤ Top 30 Industrial Internet Platforms in 2021. Retrieved from https://baijiahao.baidu.com/s?id=1724486167717494202&wfr=spider&for=pc&https://www.sohu.com/a/502121551_100210081.

economic circle, there are fewer leading industrial Internet enterprises that can provide digital transformation solutions for automobile manufacturing enterprises. Few digital transformation and reform plans lead to insufficient data flow between the upstream and downstream enterprises of the automobile industry chain and failure to improve the efficiency of the industry by comprehensively integrating resources and reducing transaction costs of all links. Moreover, automobile manufacturing enterprises are less capable of conducting real-time analysis and solving problems in the R&D, production, and sales of automobiles by using big data technology, which makes it difficult for them to well match their products with customer needs, thus affecting the quality upgrading of automobile products.

The Lag in Developing New Automobile Products Slows the Quality Upgrading of Automobile Products

NEVs and ICVs represent quality upgrades of automobile products. Auto enterprises should leverage the catalytic role of the two fields to drive the application of modular manufacturing in the whole industry, which is the critical and key point to comprehensively improve the digitization of the automobile manufacturing industry. By 2021, the output of NEVs in the Chengdu-Chongqing economic circle had reached 210,000 units.^① Although the region possesses well-known automobile enterprises such as FAW-Volkswagen, FAW-Toyota, Volvo, and Changan, most of them are automobile manufacturing factories rather than R&D headquarters. In addition, most local NEV enterprises are transformed from traditional automobile enterprises. They are better at producing engines, transmissions, and chassis while weak in providing support services related to driving motors, electronic controls, and transmissions needed by NEVs. At present, in addition to power battery enterprises such as BYD and Geely, electric motor enterprises such as Changan and Seres, and electronic control enterprises such as Chongqing Landai Powertrain Corp., Ltd. and Chongqing Yuebo transmission Co., Ltd., almost all the drive motors, electronic controls, and transmissions of NEVs in the Chengdu-Chongqing economic circle are purchased from manufacturers outside the region. Presently, the development of the NEV industry in the Chengdu-Chongqing economic circle is far from sufficient and does not have obvious technical advantages, which slows the quality upgrading of automobile products.

The Insufficient Innovation Efficiency of the Automobile Industry Restricts the Digital Transformation of the Automobile Manufacturing Industry

The Chengdu-Chongqing economic circle does not hit a very high level of advanced technology in the automobile manufacturing industry, thus hindering the digital transformation of the automobile manufacturing industry. First, there is a lack of sufficient investment in R&D. According to the statistical bulletins on the investments in science and technology in Chongqing and Chengdu, the R&D expenditure of the automobile manufacturing industry of

① Data description: In 2021, the output of NEVs in Chengdu was 58,000 (64,000 in Sichuan province), making Chengdu a major NEV producer in Sichuan province. Therefore, this paper selects Chengdu and Chongqing to reflect the output of NEVs in the Chengdu-Chongqing economic circle. The data is abstracted from the 2021 National Economic and Social Development Statistical Communique of Chengdu and Chongqing.

the two cities reached RMB 12.442 billion in 2021, accounting for 8.8% of the national total. Second, there are not many R&D centers. There are only four representative R&D institutions in the region, namely the WM Motor R&D Center, FAW-Volkswagen Digital R&D Center, Changan Global R&D Center, and IAT R&D Institute. Although several high-end platforms, such as CAICT's IoV Innovation Center and Huawei's Intelligent Network Innovation Center, have been introduced, they are still in the construction stage. Third, the software strength needs to be improved. The world has entered a new era of software-defined vehicles (SDV), in which software plays an increasingly prominent role in the design, R&D, manufacturing, and sales services of automobiles. IoV is a network that connects automobile products with various software information technologies, and its development scale can partially reflect the strength of the automobile software industry of a region. In 2021, the market size of the IoV industry in the Chengdu-Chongqing economic circle only accounted for 3.7% of that in China,^{①②} and the innovation development capability of automotive software is in urgent need of improvement. Fourth, the region is faced with insufficient innovative talent in digital technology. According to the analysis report on the geographical distribution of digital talent released by Liepin, a renowned recruitment website in China, in the first three quarters of 2021, Shenzhen and Guangzhou in the Pearl River Delta region ranked first in terms of the reserves of digital talent, and Shanghai in the Yangtze River Delta region ranked first in terms of types of digital talent, while that in Chengdu and Chongqing only accounted for 7%.^③ The Chengdu-Chongqing economic circle is not attractive enough to high-end digital talent in the automobile field, which has restricted the digital transformation of its automobile manufacturing industry.

Automobile SMEs Are Faced with Many Difficulties in Digital Transformation

There are many automobile SMEs in the Chengdu-Chongqing economic circle. Dispersed market powers, insufficient funds, and single financing channels make it difficult for the region to ensure large-scale and long-cycle investments in digital transformation. Automobile SMEs are faced with many difficulties in digital transformation, such as blocked data flow within and among enterprises, lower openness of the data in the upstream and downstream nodes of the industrial chain, the existence of choke points and breaking points in the industrial data chain, and obstacles in information interaction. This made it difficult for these enterprises to achieve horizontal integration of data, realize a management mode featuring data-driven decision-making, optimize production processes, and attain precision marketing. Most automobile SMEs have not established a sound training system for digital talent, leading to a lack of digital talent

① "Analysis of the market status and development prospects of Chengdu's IoV industry in 2021: The IoV market size expected to usher in rapid growth". Retrieved from https://www.sohu.com/a/553566619_114835.

② "Analysis of market status and development prospects of Chongqing's IoV industry in 2021: Three advantages of policies, industries and pilot areas boost rapid market growth". Retrieved from <https://baijiahao.baidu.com/s?id=1715404327122064084&wfr=spider&for=pc>.

③ "Analysis report on the geographical distribution of digital talent released by Liepin." Retrieved from <https://baijiahao.baidu.com/s?id=1716636626715828733&wfr=spider&for=pc>.

in the production, marketing, operation, and other links of automobile manufacturing, especially the interdisciplinary talents who are familiar with both production technology and information network technology. Insufficient motivation and capacity for digital transformation have made many automobile SMEs unwilling to, unconfident about, or incapable of carrying out digital transformation, which has a negative impact on the digital transformation of the automobile manufacturing industry.

International Experience and Domestic Practice

The global automobile industry is undergoing a new round of industrial transformation, and the digital transformation of the automobile manufacturing industry is an inevitable trend. The experience of the automobile manufacturing powers such as the United States and Germany and two typical automobile manufacturing clusters in China's Yangtze River Delta and Pearl River Delta regions in the digital transformation of the automobile manufacturing industry can provide references for the digital transformation in the industry in the Chengdu-Chongqing economic circle.

Digital Transformation Practice of the Automobile Manufacturing Industry in Typical Developed Countries

As global automobile manufacturing powers, the United States and Germany take the lead in the digital transformation of the automobile manufacturing industry and enjoy rich experience in this regard.

The United States's Efforts in the CASE Development in the Automobile Industry Chain

Known as the "country on wheels," the United States has three world-renowned automobile companies, namely Ford, General Motors, and Chrysler. It holds the core manufacturing technology in the automobile field. In the context of digital transformation, the federal government of the United States vigorously supports the digital transformation of the automobile manufacturing industry. Local automobile enterprises give full play to their advantages in technological innovation to develop new products such as NEVs and ICVs, and make breakthroughs in advanced automobile technologies such as autonomous driving and IoVs, gradually occupying a higher position in the CASE development in the automobile industry chain.

The digital transformation of the American automobile manufacturing industry is closely related to the strong policy support of the federal government. Since 2008, the US federal government has successively introduced policies such as the Advanced Technology Vehicles Manufacturing (ATVM) Loan Program worth USD 25 billion, Economic Stimulus Plan for new energy and other fields worth USD 787 billion, the R&D Subsidy Act for NEVs worth USD 4.4 billion and the *National Strategic Plan for the Manufacturing Industry* to encourage and support automobile companies to carry out digital transformations. An IBM report shows that 83% of

executives interviewed have recognized the strategic value of data in the automobile industry.^① At the same time, the federal government has introduced a national energy policy to implement individual income tax credits, issue purchase subsidies, and grant double credits for those who buy NEVs. It has also strengthened fiscal, taxation, and financial support for the construction of supporting facilities for NEVs. In addition, the US federal government has also issued the *Intelligent Transportation Systems (ITS) Strategic Plan 2015-2019* and the *Federal Automated Vehicles Policy* to promote the development of ICVs.

The US continuously uses its local technological advantages to enhance its technological innovation capability in the automobile field. The US is home to eight of the world's top 10 IT companies, and the collaboration of high-tech companies in Silicon Valley provides a technological cluster required by the automobile industry. The US is a forerunner in introducing smart digital factories in automobile manufacturing. Automobile enterprises have also increased their R&D investment in software development and autonomous driving. According to the latest list of autonomous driving competitiveness released by consulting firm Guidehouse in 2021, Google's Waymo topped the list again, and 7 American companies were listed among the top 10.^②

Germany Takes Multiple Measures to Promote the Digital Transformation of Automobile Enterprises

Germany is the birthplace of the world's modern automobile and has a profound background in automobile manufacturing. The advantage of the digitalization of the German automobile manufacturing industry lies in the use of digital technology to innovate automobile products and business models and the emphasis on the digital transformation of automobile SMEs.

Germany attaches great importance to the development of the NEV industry. Germany has launched a future fund program to support the development of the automobile industry. The country has granted one billion euros to support the construction of digital transformation networks for the German automobile manufacturing industry and provide digital solutions and paths for automobile SMEs to practice digital transformation, helping Germany become the largest electric vehicle market in Europe. Germany has long realized the importance of the battery supply chain in the development of NEVs. The country has taken the lead in promoting European countries and enterprises to establish the European Battery Alliance and spearheaded the launch of Important Projects of Common European Interest (IPCEI), aiming to support the R&D and innovation of battery technology in Europe. In addition, Germany has developed an advanced virtual exhibition hall to improve the consumer experience. The Digital ID card ensures the real-time information sharing of auto parts between manufacturers and suppliers. In this way, it can drive innovations in products and business models, upgrade product quality, and improve the efficiency of the industry with digital technology.

^① American Media: Digital transformation leads to recovery in the automotive industry. Retrieved from <https://m.gmw.cn/baijia/2020-04/27/1301184500.html>.

^② IEV. Authoritative rankings of autonomous driving released: Tesla is at the bottom while Baidu ranks top". Retrieved from <https://baijiahao.baidu.com/s? id=1698366560060847492&wfr=spider&for=pc>.

Germany pays close attention to the digital transformation of automobile SMEs. The German government has launched a series of policies to promote the digital transformation of SMEs, including the *Action Plan for Digital Transformation of SMEs*, the *Digital Strategy 2050*, and the “Digital Now” Program. With the help of these policies, a framework system for the digital transformation of SMEs has been gradually formed, which is financed by large funding programs such as Industry 4.0 for SMEs and numerous small funding projects, assisted by multiple competence centers at the technic level, and distinguished by various communication forums. At the same time, Germany has incubated many high-level industrial clusters, gathering cutting-edge enterprises, talent, scientific research institutions, and other resources to promote the digital transformation of automobile SMEs. For example, in the Technology Network it’s OWL, around 200 manufacturing enterprises, 18 scientific research institutions, and six universities have joined forces to develop solutions for the digital transformation of automobile SMEs. It has provided digital transformation services for nearly 400 machinery factories and automobile SMEs in the Ostwestfalen-Lippe region, promoted the optimization of the organizational structure and mode of automobile SMEs, and facilitated the digital transformation of the automobile manufacturing industry.

Exploration of the Digital Transformation of the Automobile Manufacturing Industry in Typical Areas of China

The Yangtze River Delta and Pearl River Delta regions are large and leading automobile manufacturing clusters in China, with a profound background in this regard. In recent years, faced with opportunities for the development of the digital economy, the two regions have vigorously deepened the integration of digital technology with the automobile industry, taken the lead in implementing the digital transformation of the automobile manufacturing industry, and accumulated a lot of replicable and promotable experiences.

Giving Full Play to the Fundamental Role of New Infrastructures in the Digital Transformation of the Automobile Manufacturing Industry

In terms of charging facilities for NEVs, the Yangtze River Delta and Pearl River Delta regions are vigorously expanding the coverage of charging facilities, laying a foundation for the promotion and popularization of NEVs. Data from the China Electric Vehicle Charging Infrastructure Promotion Alliance and Intelligence Research Group showed that by the end of 2021, a total of about 341,000 public NEV charging piles were available in the Yangtze River Delta region and the number in the Pearl River Delta region was 182,000.^① In terms of the industrial Internet of automobile and auto parts, both the Yangtze River Delta region and the Pearl River Delta region attach great importance to the building of the industrial Internet, and have cultivated a large

① New Energy Vehicle Association. “Summary of China’s charging pile operation in 2021 and industry trend forecast in 2022”. Retrieved from https://view.inews.qq.com/k/20220112A06D5U00?web_channel=wap&openApp=false.

number of advanced industrial Internet enterprises such as Foxconn Industrial Internet (FII), Rootcloud, and Huawei that are providing digital tools and digital transformation solutions for the automobile and automobile parts industry. Established in 2014, XCMG HANYUN, based in Jiangsu province, has now developed more than 350 industrial agreements and 1,542 industrial apps, successfully connecting nearly one million units of construction machinery and equipment with its excellent capabilities of equipment networking, data acquisition, and edge computing. The company has built a platform for logistics control and services of NEVs for Guangdong Guangzhou Xieli Intelligent Technology Co., Ltd., improving its logistics transportation capacity for NEVs by 19%, transportation efficiency by 35%, and customer satisfaction by 24%.^① Founded in 2017, Huawei Cloud in Guangdong, a latecomer in the industrial Internet field, has embraced rapid development under favorable policies and innovative environments. In 2021, Huawei Cloud ranked fifth in the global IaaS market, with a global share of 4.61%. The company has built a brand new “cloud marketing service platform” for Dongfeng Honda, accelerating the establishment of new 4S stores of Dongfeng Honda across the country, increasing the product launching speed by six times, and providing users with a refreshing driving experience.^② It has also built IoV platforms for GAC MITSUBISHI, Foton Motors, and JAC to facilitate their digital transformations.

Highlighting the role of Technological Innovation in Promoting the Digital Transformation of the Automobile Manufacturing Industry

The Yangtze River Delta and Pearl River Delta regions have long taken technological innovation as the key to promoting digital transformations and the upgrading of the manufacturing sector. The two regions have attracted a large number of next-generation innovative and entrepreneurial enterprises by virtue of their advantages, such as quick access to information and convenient transportation and have incubated a large number of advanced automobile manufacturing enterprises such as SAIC, Geely, NIO, BYD, and Xpeng Motors by continuously introducing innovation support policies and increasing investments in innovation. According to the 2021 China Automobile Patent Statistical Report, SAIC, Geely, Chery, JAC, NIO, and Hozon Auto in the Yangtze River Delta region occupied six of the top 20 automobile patent disclosures in China, with a total of 11,649 automobile patents disclosed and 8,657 granted. GAC Group, BYD, China Evergrande New Energy Vehicle Group, Xpeng Motors, and Baoneng Auto in the Pearl River Delta region ranked in the top 20, with 7,896 automobile patents disclosed and 5,322 granted. In addition, SVOLT, BYD, and GAC in the Yangtze River Delta and Pearl River Delta regions were three out of the Top 10 NEV patent innovators.^③

① Case study of Xieli Group's IoV big data platform. Retrieved from <https://www.hanyunplat.com/show-12-3-1.html>.

② “Huawei Cloud saw a year-on-year growth of over 30% in 2021, and its excellent performance goes beyond market expectations”. Retrieved from <https://m.gmw.cn/baijia/202203/31/35627162.html>.

③ “2021 China automotive patent statistics results released”. Retrieved from https://www.sohu.com/a/518673833_120133310.

Supporting the Development of the NEV Industry and Facilitating the Digital Transformation of the Automobile Manufacturing Industry

The Yangtze River Delta and Pearl River Delta regions are vigorously laying out the NEV industry by introducing a series of policies and measures to encourage and support the development of NEVs and ICVs. Shanghai in the Yangtze River Delta region alone has introduced 12 relevant policies from 2018 to 2021.^① Thanks to the policy support, the Yangtze River Delta and Pearl River Delta regions have fostered new car manufacturers such as NIO, WM Motor, BYD, and Xpeng Motors. At the same time, the two regions have attracted many European, American, and Japanese foreign-funded NEV enterprises, such as Tesla, with their superior development environment and profound industrial bases. They are committed to the manufacturing of batteries, motors, and electronic control core parts. They have built relatively complete supporting facilities for the NEV industry, promoting the digital transformation of the automobile manufacturing industry. By 2021, the output of NEVs in the Yangtze River Delta region had reached 1.339 million units, accounting for about 38% of the country's total, making it the most important NEV production base in China. The number of the Pearl River Delta region was 523,900, with Guangdong province being a national demonstration benchmark for the application and promotion of NEVs.^②

Relying on Industrial Parks and Alliances to Promote the Digital Transformation of the Automobile Manufacturing Industry

Industrial parks and alliances are vehicles for gathering enterprises and innovation factors and important support for accelerating industrial digital transformations. In recent years, the Yangtze River Delta region has successively established the G60 Sci-tech Innovation Corridor Auto Parts Cooperation Demonstration Park, G60 Sci-tech Innovation Corridor NEV, and ICV Industry Alliance, Intelligent Driving Industry Alliance, and Yangtze River Delta NEV Industry Chain Alliance. More than 100 automobile industrial parks and eight national high-tech zones for the development of the automobile and new energy industries have been built there (Xu, 2021). Dozens of provincial-level smart factories and demonstration zones for automotive digital transformation products have been built, attracting high-tech projects covering IoVs, chips, and intelligent cabins and CASE automobile enterprises such as NIO, Li Auto, and Pony.ai. The Pearl River Delta region has a number of well-known automobile enterprise headquarters and automobile production bases. Relying on the two core cities of Guangzhou and Shenzhen, it has formed a well-established NEV industry cluster focusing on GAC and BYD, with strong development strength and broad prospects. The two regions have gathered various innovative factors by relying on their respective industrial parks and alliances, and created a new situation

① "Summary of the latest policies of Shanghai automobile industry in 2021". Retrieved from <https://www.163.com/dy/article/GSI3R9350514810F.html>.

② The data is abstracted from Statistical Communiqué of the People's Republic of China on the 2020 National Economic and Social Development. Guangzhou, Zhaoqing, and Shenzhen in the Pearl River Delta region produced 523,900 NEVs in 2021 (535,000 in Guangdong province), which accounted for the lion's share of the province's total. Therefore, the three cities are selected to reflect the output of NEVs in the Pearl River Delta region; Shanghai, Jiangsu, Zhejiang, and Anhui are selected to reveal situations in the Yangtze River Delta region.

for the NEV industry, characterized by smooth data sharing among the upstream and downstream enterprises of the automobile industry chain and high digitalization of enterprises, enhancing the role of leading enterprises in promoting digital transformations.

Summary and Promotion of Typical Experiences at Home and Abroad

The United States, Germany, the Yangtze River Delta, and the Pearl River Delta regions in China have achieved remarkable results in the practice and exploration of the digital transformations of their automobile manufacturing industries and have accumulated a lot of replicable and promotable experience in this regard, which can provide references for the digital transformation of the automobile industry in the Chengdu-Chongqing economic circle.

Taking the Expansion of New Infrastructures and Promotion of NEVs as a Necessary Means to Upgrade the Quality of Automobile Products

NEVs and ICVs represent the strategic direction of the transformation and upgrading of the global automobile industry. The US and German governments have attached great importance to the development of NEVs and ICVs. They tend to provide large amounts of funds to support enterprises to research and develop NEVs and ICVs, and related core technologies to accelerate quality upgrades for these automobile products. The Yangtze River Delta and Pearl River Delta regions are taking advantage of the development of the digital economy to accelerate the distribution of digital infrastructures for automobiles and build Internet platforms for the automobile industry to provide a solid support for the development of NEV and ICV industries. On this basis, the regions vigorously increase financial subsidies for NEVs, attract social investments from various channels, and encourage consumers to buy NEVs and related products, thus maintaining the market size and competitive edge of NEVs, and promoting the quality upgrades of automobile products.

Taking Technological Innovation as the Key Link to Improve the Efficiency of the Automobile Manufacturing Industry

The United States and Germany, as well as the Yangtze River Delta and the Pearl River Delta regions in China, all attach great importance to the improvement of the independent innovation capability of automobile enterprises. Relying on Silicon Valley and other high-tech industrial clusters, the United States focuses on developing automotive software, IoVs, and other high-end automotive technologies. It leads the CASE development in the automobile industry chain. Germany seizes the opportunities for electric vehicle development, takes the initiative to develop core battery technologies of NEVs, and explores the technology application of automobile business models in advance. The country also spearheaded the establishment of the European Battery Alliance, and strived to master the core technology of NEVs. The Yangtze River Delta and Pearl River Delta regions are highly concerned about the three key technologies of electric vehicle (EV) powertrain integration, automotive body integration manufacturing, and automotive lightweight manufacturing and have pooled various ideas to solve the technical difficulties facing

the automobile manufacturing industry in the digital transformation. The regions pay special attention to the electrified, intelligent, connected, and lightweight development of automobile manufacturing technologies to strengthen their innovation capability of core technologies and continuously improve the technical level and core competitive edges of their automobile manufacturing industries.

Giving Priority to the Digital Transformation of Automobile SMEs to Accelerate the Digitalization of the Automobile Industry

The automobile industry features a long industrial chain involving many auto parts manufacturing SMEs. Accelerating the digital transformation of automobile SMEs will contribute to the building of a digital ecosystem throughout the whole industrial chain and process of the automobile industry, thus promoting the digital transformation of the automobile manufacturing industry. Fully aware of the importance of promoting the digital transformation of automobile SMEs, Germany has built a framework system for the transformation of automobile SMEs in line with its actual situation to provide policy and institutional support for the digital transformation of automobile SMEs. At the same time, relying on its advantageous automobile industry cluster, Germany has set up competence centers and other service organizations throughout the country to provide professional support for the digital transformation of automobile SMEs and improve their core capabilities through digital transformations. The Yangtze River Delta region has explored and refined excellent digital solutions for automobile SMEs and built an industrial innovation ecosystem to accelerate the transformation of their production modes, business models, and organizational structures, thus improving their digital transformation capabilities. The Pearl River Delta region has made all-out efforts to make industrial Internet platforms and technology supply available for automobile SMEs to facilitate their digital transformations. The region has increased its investments in the digital transformation of automobile SMEs and granted full-cycle rewards and subsidies for their digital transformation so that automobile SMEs can get on the digital express train and bravely and willingly become capable of making the digital transformation.

Relying on the Collaboration among Industrial Parks and Alliances to Optimize the Organizational Mode of Automobile Enterprises

The German automobile industry features contagious distribution in space and agglomerative development in the industrial chain and attaches great importance to optimizing the organizational mode of automobile enterprises through the collaboration of different industrial parks. The country has established an automobile industry alliance composed of several large automobile groups, including Daimler (the parent company of Mercedes), BMW, and Audi (subsidiaries of VW), and spearheaded the establishment of the European Battery Alliance together with other European countries and enterprises. The United States optimizes the spatial layout of its automobile industry clusters and improves the management abilities of enterprises by following the ecological, innovative, connected, brand-oriented, and globalized development philosophy. American automobile enterprises have established enterprise alliances, large automobile groups,

and industrial alliances through resource sharing and cooperation to facilitate the optimization of the organizational structure of their automobile industry. Automobile manufacturing parks in the Yangtze River Delta and the Pearl River Delta regions show a multi-functional and specialized development trend and high coordination among automobile enterprises in their parks. Relying on the complete automobile industry chain in the parks and leading digital technologies, the two regions have attracted many high-quality automobile projects at home and abroad. Efforts have also been made to continuously integrate various innovation elements and promote mutual exchange and learning, as well as collaborative innovation among major automobile enterprises to jointly improve the intelligent management capability of automobile enterprises. In terms of organizational modes, enterprises in the two regions have shifted their focus from relying on supply chain organizations to relying on platform information organizations, from competition in products, technologies, and the industrial chain to the regional ecosystem, from enterprise innovation to social innovation. The Yangtze River Delta and Pearl River Delta regions emphasize the establishment of several industrial alliances regarding IoVs and NEV hydrogen fuels, which have greatly improved the development of ICVs and NEVs.

Feasible Paths for the Digital Transformation of the Automobile Manufacturing Industry in the Chengdu-Chongqing Economic Circle

The digital transformation of the automobile manufacturing industry is of great significance to the high-quality development of the automobile manufacturing industry in the Chengdu-Chongqing economic circle. The application of 5G and big data technologies can break isolated data islands, improve the efficiency of automobile manufacturing enterprises in product release and collaborative R&D among different places, and extend the industrial and value chains of the automobile industry, thus promoting the quality upgrade of automobile products. The wide application of digital technology can effectively match the supply and demand information of enterprises across regions and segments and connect the participants of the entire industrial chain. In addition, it can further shorten the supporting radius of the automobile industry and create a closer connection between the upstream and downstream supporting enterprises of the industrial chain, thus improving the efficiency of the industry. Internally, the application of data and digital technology can streamline the cumbersome management modes of automobile enterprises and improve the accuracy of management decision-making and the work efficiency of employees. Externally, it can promote the transformation of enterprises from traditional organizations into new ones, featuring shared platforms, and can promote huge changes in enterprises' digital management capabilities. Therefore, by examining the mechanism of action of the digital transformation of the automobile manufacturing industry and drawing on the practical experience of the United States, Germany, Yangtze River Delta, and Pearl River Delta regions, we put forward feasible paths for the digital transformation of the automobile manufacturing industry.

Smoothing the Dual-core Data Chain to Facilitate the Digital Transformation of the Automobile Manufacturing Industry

We should smooth the data chain between Chengdu and Chongqing and enhance the connectivity of the automobile industry by sharing data elements to promote quality upgrades of automobile products and the improvement of industrial efficiency. First, we should continue to promote the joint construction and sharing of an ICV information platform and a supply and demand information matching platform between the dual-core areas of Tianfu New Area and Liangjiang New Area for the development of the automobile industry in the Chengdu-Chongqing economic circle. Efforts should also be made to build a resource-sharing network for the automobile industry to promote data connectivity, optimize resource allocation, and improve the production efficiency of the industry. Second, we should give full play to the economic advantages and development potential of dual-core areas and introduce more excellent industrial Internet enterprises and platform projects such as Geely's Geega. In the automobile R&D and production links, big data platforms such as automobile simulation, low-code development, and agile software development can be built to extend to the front end of the manufacturing link. We should integrate consumer demand information with shared information about automobile resources, pay attention to creative design, technology R&D, and achievement commercialization to increase the proportion of high-end automobile products. In the sales and after-sales service links, big data platforms such as cloud-based marketing service systems can be built to extend to the rear end of the manufacturing link. In addition, efforts can also be made to drive the digitalization of the R&D, production, and marketing of the automobile industry in the Chengdu-Chongqing economic circle and improve the quality and added value of automobile products.

Developing the NEV Industry and Upgrading the Quality of Automobile Products

Chongqing has obvious advantages in automobile manufacturing, while Chengdu enjoys stronger innovation power. Therefore, we can give full play to their respective advantages to achieve efficient division of labor and integrated development and jointly tackle key technical problems in the development of NEVs and ICVs to improve the added value of automobile products. First, we should join forces to build the "Chengdu-Chongqing Hydrogen Corridor," "Chengdu-Chongqing Electric Corridor," and "Chengdu-Chongqing Intelligent Driving Corridor," promote the establishment of the Chongqing Automotive Software and Chip Research Institute, and provide more financial support and preferential policies to attract automobile manufacturing enterprises and automotive technology R&D institutions. We should pool together advantageous innovation resources, build a series of national NEV and ICV innovation platforms with the Longquanyi Intelligent Automobile Industry Functional Zone in Chengdu as the center, and expand the product matrix of NEVs around the Liangjiang New Area Automobile Production Base in Chongqing. Efforts should also be made to accelerate the breakthrough of innovative technologies such as automobile electrification and intelligentization to promote the development of the new energy vehicle industry. Second, we can expand the coverage of NEV charging

facilities in the region and call on charging pile enterprises in the region to establish professional teams and industrial alliances to unify data standards of charging piles and establish standard systems for charging pile products, thus facilitating the connectivity of NEV charging piles, and ensuring the use of NEV products.

Achieving “Corner Overtaking” in the Digital Transformation of the Automobile Manufacturing Industry with Digital Technology

We should further enhance the scientific and technological innovation capability and improve the technical level of the automobile manufacturing industry in the Chengdu-Chongqing economic circle, achieving corner overtaking in the digital transformation of the automobile manufacturing industry with digital technology. First, we should always consider the situation across the board, break administrative restrictions, and strengthen the open sharing of digital information. We should also support innovation-oriented leading automobile enterprises such as Changan and Seres in Chongqing to build innovative industry alliances in collaboration with the upstream and downstream enterprises in the region and speed up the establishment of the automobile intelligent manufacturing innovation center, auto parts sharing and testing center, and the automobile technology trading platform in the Chengdu-Chongqing economic circle. Second, we should call for collaboration among cross-regional automobile enterprises, universities such as Sichuan University, the University of Electronic Science and Technology of China, Southwest Jiaotong University, Chongqing University, and research institutions for the establishment of the industrial technology research institute. Joint efforts should also be made to apply for national projects for intelligent vehicle technology research and support top universities at home and abroad to cooperate with research institutions to build research institutes and centers in the Chengdu-Chongqing economic circle, thus fully supporting breakthrough achievements in the core technologies needed for the digital transformation of automobile manufacturers such as automobile simulations and digital twins.

Jointly Building Automobile Industrial Parks to Promote the Digital Transformation of the Automobile Manufacturing Industry

We should jointly build automobile digital industrial parks and introduce policies to support the digital transformation of these parks. Specifically, we should not only encourage “dual-core” automobile manufacturing industrial parks to take the lead in digital transformation, but also accelerate the digital transformation of the automobile industrial parks in the core areas as well as the south and north areas of the Chengdu-Chongqing economic circle. We should vigorously promote the digital transformation of key automobile industrial parks, such as Longquanyi’s Intelligent Automobile Industry Functional Zone in Chengdu, Jianzhou’s ICV and NEV Industrial Park, and Chongqing’s Zhonglian International Automobile Equipment Industrial Park to improve the level of digitalization and intelligent manufacturing of enterprises. The automobile digital ecosystem helps to connect different regions and integrate advantageous automobile resources. We should take leading enterprises with high digitalization as key nodes and promote data sharing

by means of digital platform procurement and production equipment sharing to attract more automobile enterprises to the Chengdu-Chongqing economic circle, thus gradually improving the digitalization of automobile enterprises.

Addressing Problems Facing Automobile SMEs in Their Digital Transformations via Targeted Policy Tools

There are many automobile manufacturing SMEs in the Chengdu-Chongqing economic circle, so it is necessary to do overall planning and develop accurate combinations of special fiscal, taxation, and financial policies and to encourage financial institutions of various types to increase credit support for the digital transformation and upgrading of automobile manufacturers to provide them with personalized and targeted financial products and services. We should have in place such flexible financing measures as “stock rights + creditor’s rights” to provide financing support for the digital innovation activities of automobile enterprises. We should encourage qualified new vehicle manufacturers to go public and promote various platforms to explore and carry out credit loans, financial leasing, and other financial services based on real-time production and operational data. Efforts should also be made to expand capital sources of automobile enterprises in digital transformation by enhancing credit and empowerment and promoting the linkage of investments and loans to reduce their transformation costs. Finally, Chengdu and Chongqing should add automobile-related majors in colleges and universities and jointly set up automobile digital training institutions to deliver and reserve technical talent for the digital transformation of the automobile manufacturing industry. The two cities should improve policies regarding talent introduction and training, develop a multi-level talent echelon for the digital transportation of the automobile manufacturing industry by increasing salary subsidies, building a flexible talent flow mechanism, and setting up reasonable talent promotion methods to provide talent support for the digital transformation of automobile SMEs.

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