Strategic Study of CAE 2023 Vol. 24 No.2
DOI 10.15302/J-SSCAE-2022.02.002

Strategy for Improving Product Quality of Manufacturing Industry in China

Zhang Hao [1, 2], Zhang Gang [2], Jiang Jiadong [1, 2]

1. AVIC China Aero-Polytechnology Establishment, Beijing 100028, China
2. Key Laboratory of Quality Infrastructure Efficacy Research, Beijing 100028, China

Abstract: Currently, the product quality of China's manufacturing industry is uneven and has a notable gap with that of developed countries. Improving the quality of manufactured products is vital for upgrading China's manufacturing industry and promoting the core competitiveness of the industry. In this study, we first analyze the development characteristics regarding the quality of the manufacturing industry, and then examine the development trend and prominent problems regarding the product quality of China's manufacturing industry. While summarizing international experiences, we propose several suggestions for product quality improvement. Specifically, China should (1) clarify the strategic positioning of product quality development and strengthen the coherence of national quality policies; (2) focus on the needs of future industrial development by implementing three action plans; (3) accelerate the innovation of quality management theories, technologies, and tools under the guidance of digital transformation; (4) integrate the industrial quality infrastructure to support the product quality improvement; (5) reconstruct the quality development environment to promote enterprises' willingness in improving product quality; and (6) maximize the institutional advantages of the country to implement foundation projects for improving product quality.

Keywords: manufacturing; quality improvement; product quality; quality assurance; quality infrastructure

1 Introduction

Manufacturing is the foundation of a strong country and the core of international competition. At present, as the global trade environment has deteriorated, China's manufacturing industry is facing many difficulties in development, such as the accelerated transfer of domestic industries to the international market, the lack of access to key products in the industrial chain, and the strangulation of core technologies. Quality plays a key role in the evolution and reshaping of global manufacturing competition pattern. Improving the quality of physical products not only helps expand market share by enhancing the quality of domestic and foreign consumer recognition but can also lead to the formation of new industries by stimulating new consumer demand. Strengthening quality control in industry can boost the ability to industrialize achievements in independent innovation to accelerate the completion of self-supporting, safe, and highly efficient development goals. Additionally, it can increase the stickiness of industrial clusters and support industrial transformation and upgrading. Therefore, during a critical period when the competition pattern of the global manufacturing industry has been significantly adjusted, China's economy has entered a state of "new normal", and the manufacturing industry is large but not strong, improving the quality of manufacturing has become an urgent issue.

The current premise for improving product quality in China's manufacturing industry is to identify the factors affecting it. The existing literature on product quality mainly analyzes product quality improvement from two perspectives—macro and micro—while focusing specific factors such as income level, enterprise productivity, and

---

Received date: January 8, 2022; **revised date:** January 25, 2022

Corresponding author: Zhang Hao, Senior Engineer from the China Institute of Aeronautical Technology. Major research fields include quality infrastructure, macro quality evaluation, and standardization strategies. E-mail: wenyi1@126.com

Funding program: CAE Advisory Project "Strategic Research on Strengthening Industrial Foundation and Upgrading Industrial Chain" (2021-HYZD-08)

Chinese version: Strategic Study of CAE 2022, 24 (2): 038–047

Cited item: Zhang Hao et al. Strategy for Improving Product Quality of Manufacturing Industry in China. *Strategic Study of CAE*, https://doi.org/10.15302/J-SSCAE-2022.02.002

production factor endowment. From a macro perspective, countries with higher income levels have a stronger preference for high-quality products, and market demand for high-quality products can force them to produce more high-quality products, thus forming a virtuous circle [1]. In terms of factor endowments, endowment of technology raises product quality more than endowment of labor while the capital intensity in production technology affects the products' unit value [2]. Import competition is also an important factor influencing the level of product quality, particularly when two countries have comparable quality levels, and increased competition caused by tariff reductions is conducive to improving product quality [3]. From a micro perspective, firms' production efficiency and workers' skill level are key factors affecting product quality [4,5]. In addition, tariff reductions [6–9], exchange rates [10], government subsidies [11,12], firm productivity [13], ownership [14], capital intensity [15], and imports of intermediate goods [16] are key factors that affect product quality. Since reform and opening up, the quality of China's manufacturing products has continuously risen, the product range is extremely rich, and the quality and safety guarantee has steadily improved. Indeed, products bearing the label "Made in China" are sold worldwide. However, there are still imbalances and issues related to insufficient quality of products that make it difficult to meet the demand of consumer upgrading and guarantee national economic and defense security; therefore, continuing to improve the quality of manufacturing products remains a critical research issue.

Improving the quality of manufactured products is a systematic project that must simultaneously promote the development of various aspects of quality, including strategies, technology, control, infrastructure, and ecology. In the competition for quality in the global manufacturing industry, countries worldwide focus on solving dynamic issues and capacity problems that impact the development of product quality. In conclusion, to promote the development of manufacturing product quality at the national level, it is necessary to solve not only the strategic issues of quality development but also the technical and control issues, as well as to consolidate the infrastructure of quality industry and ecology that are the pedestals of quality development. This study outlines the high-quality development of the manufacturing industry, analyzes the situation and characteristics of developing product quality in the manufacturing industry in China, and highlights prominent issues. Finally, we suggest some countermeasures for improving product quality in China' manufacturing sector by reviewing and combining the international experience in this area.

2 Manufacturing quality development characteristics

2.1 Re-industrialization and counter-globalization processes intensify global manufacturing quality competition

In recent years, the industrialization and re-industrialization strategies of developing and developed economies, as well as the wave of counter-globalization are reshaping the competitive global landscape of manufacturing. Various elements (e.g., the rise of emerging market countries, preferential policies for manufacturing in developed countries, import and export trade controls, and the application of innovative technologies) drive the repositioning of various value chains, such as innovation, labor- and resource-intensive product, and regional production, in different economies [17]. With the deepening of industrialization, globalization, and informatization, the manufacturing industry are facing the "new normal" of global overcapacity, convergence of manufacturing quality, and acceleration of product innovation. Additionally, new problems, such as key products and core technologies in the industrial chain being "weaponized" and the global value chain having to be localized and closed have emerged. However, achieving quality remains the primary strategic objective of manufacturing development worldwide and has been given a new connotation to cope with the big changes in manufacturing development.

Currently, the competition for manufacturing quality centers on the battle for producing diversified and innovative products that feature high safety and reliability, strong maintainability, and high service efficiency throughout the entire product life cycle. The additional values of products and industries directly affects the strength and power of quality development in manufacturing and profoundly affects the wealth growth and welfare distribution of the country and society. The continuous deepening of the re-industrialization policy and the increasingly severe wave of counter-globalization have highlighted the key role of industrial standard-setting and chain governance in the development of manufacturing quality.

2.2 Scientific and technological progress and industrial change trigger a major adjustment in the paradigm, essentials, and techniques of quality control

Technological progress and industrial changes have profoundly altered the production mode of manufacturing industry and reshaped its quality control mode. For example, manufacturing processes have shifted from

DOI 10.15302/J-SSCAE-2022.02.002

separation to integration, the relative importance of input factors has shifted, digital production has become a trend in manufacturing development, the share of customized production has increased, and services have become an important source of value for products. Changes in production methods and competitive kernels drive the quality control paradigm to accelerate the transformation to digitalization, intelligence, systematization, and zero-defect, ultimately leading to a fundamental adjustment in the key points of manufacturing quality control. In terms of product quality characteristics, quality control has changed from focusing on product quality to focusing on both product and service quality. Regarding production methods, quality control has shifted from concentrating on scale production quality alone to include a focus on personalized quality. With respect to production processes, quality control has been expanded from manufacturing quality to both manufacturing quality and design quality. In terms of input factors, quality control now includes not only traditional input factors but also digital input factors. In line with the transformation trend of digitalization, networking, and intelligence of quality control, countries have focused on innovating technologies and methods of quality control to promote the innovation and application of digital quality control technology, zero-defect quality control technology, modern supply chain quality control technology, and advanced industrial quality infrastructure [18].

2.3 Global competition and industrial change requires reshaping the quality ecosystem

Profound changes in the connotation of quality development and control techniques in the manufacturing industry require a reshaping of the ecology of quality development in the manufacturing industry to meet the industry's future needs for high-quality manufacturing. In terms of the rule of law on quality, it is necessary to consider the relationship between accelerating product innovation and protecting consumer rights to create a relaxed market environment conducive to technological innovation and to prevent damage to consumers and sustainable development caused by the safety risks inherent in new technologies and products. In terms of quality policy, a deeper expansion of opening up requires full participation in the development and implementation of the trade rules that are globally recognized. Coping with the risks of reverse globalization necessitates sustained implementation of quality strategies in accordance with internationally accepted practices, support for quality development in innovation and safety areas, and improved discourse in industrial chain governance. In terms of quality culture, we will shift our focus from the characteristics of product quality to the role of quality culture and create a modern quality culture that cares about customers' well-being and considers stakeholders' demands.

3 Developing status of China's manufacturing product quality

3.1 Quality structure, efficiency, and brands

In terms of the quality structure, China's manufacturing industry is mainly concentrated in low-end areas and part of the mid-range market. There is a surplus of low-end products, and high-quality, high-value-added products depend on imports. In 2020, China's quality-sensitive industries accounted for 26.93% of all industries, compared with 34.30% in the United States (U.S.), 42.40% in Germany, 40.38% in Japan, and 50.93% in Switzerland, indicating that a significant gap between China's quality structure and that of developed countries remains. Although China's economy has made significant progress since the reform and opening up, the relative quality of China's exports has declined [19]. However, this does not necessarily mean that the absolute quality of exports has declined but rather that other countries' products may have improved. The share of capital goods and components in China's exports has risen, and their relative quality is low (i.e., only 38%–52% of the world average), which, in turn, reduces the overall quality level.

In terms of quality efficiency, Chinese enterprises generally lack core technologies and quality competitiveness, making it difficult for them to obtain quality premiums from their products. Consequently, they differ from firms in developed countries in terms of the effectiveness of production factor utilization, the level of labor productivity, and the value of export units. In recent years, China's manufacturing value-added rate has been over 10% lower than that of developed countries such as the U.S., Japan, and Germany, and the gap has yet to significantly narrow. China's manufacturing labor productivity was equivalent to that of the U.S. in the 1940s, Japan in the 1970s, Germany in the 1950s, and South Korea in the 1980s [20]. As for the unit value of exports, the unit value of China's exports in 2019 was 13.44, compared with 26.68 in the U.S., 53.52 in Germany, and 34.16 in Japan in the same period, showing that the unit value of exports of Chinese enterprises is, generally speaking, far below that of developed countries.

In terms of quality brands, private brand construction faces low-end lock-in. Global Sources and its business management media, World Manager, conducted a survey of the overseas buyer community on private brand development among Chinese export suppliers, the results of which indicated that the percentage of companies choosing to own their own brands has increased [21]. Because the popularity and reputation of Chinese suppliers' own brands are mostly based on high-cost performance, high-end brands and products are relatively lacking, which leads to low brand awareness and reputation. Complicating matters, brand upgrades in the international market have been blocked. According to the *Survey Report on the Survival of Foreign Trade Enterprises in 2020*, Chinese enterprises' shift from the low end of the supply chain to the middle and high ends has alarmed traditional market controllers such as Europe, the U.S., and Japan, causing Chinese enterprises to encounter increasing resistance in the international market.

3.2 Reliability of key core products in the industry chain

The low quality of key core products in the industrial chain is a prominent problem leading to dependence on imports of key core products (e.g., industrial master machines, high-end chips, and basic components and materials), which bear the risk of being cut off (Table 1) [22]. The *China Robot Quality Annual Report 2018* showed that there are several major product quality pain points for robots, including functional safety, key electrical components, information security, software quality, and operating systems [23]. Several large photovoltaic (PV) power plants and a large number of residential PV systems built successively in the western region of China were found to have serious PV product quality problems, and over half of the component products of some systems had significant decay in power generation efficiency [24].

Table 1. Comparison of product quality and reliability.

Fields	Current level in China	International advanced level
Computer numerical control (CNC) machine tools	The average time between failures of the whole machine is around 900 hours.	The average time between failures is 5000 hours
High pressure plunger pump	Product life is 1/2 of imported products, the average trouble-free operation time is less than 2000 hours	The average trouble-free operation time is over 8000 hours
Agricultural machinery	The average time between failures is about 500 hours for excavators, 300 hours for loaders, and 270 hours for forklifts.	The average time between failures of similar products is about 1000–3000 hours
High-end aluminum alloy welding wire	Hydrogen content of aluminum (AI) welding wire products is 0.15 mL/100 g Al, grain size is generally 2–3 grade	The hydrogen content reaches 0.10 mL/100g Al, and the grain size is grade 10

In the field of sensors, the functional stability and consistency of the points in the sensor array are poor. The static accuracy error rate of multidimensional force sensor products is 1%–2%, and the dynamic coupling error is 5%–10%, which does not match the market demand. Using foreign sensor products, the Chinese electric power sector can operate for three years without maintenance, whereas quarterly maintenance is required when using domestic products. Currently, manufacturing equipment for high-end sensor cores relies primarily on imports. The main performance indicators of processes and products independently developed in China and the service life are to 1–2 and 2–3 orders of magnitude worse than those in foreign countries, respectively. Lightweight materials such as aluminum alloys are widely used in automobiles, aerospace and other fields. Manufacturing of welding wire built from a high-end aluminum alloy (a key welding material), depends mainly on imports in China. The hydrogen content of Chinese aluminum welding wires is 0.15 mL/100 g Al, while the international leading level has reached 0.10 mL/100 g Al. Additionally, Chinese wire grain size is generally of 2–3 grades, while that of foreign wire is of grade 10.

3.3 Product safety and consumer quality recognition

Compared with advanced international levels, there are gaps in product quality, safety standards, and physical quality in China. Consequently, many consumers lack confidence and fail to recognize the quality of products made in China. In terms of safety standards, laws, and regulations, as well as technical standards related to safety, regulatory, and environmental requirements in some areas lag far behind market demand. For example, milk somatic cell count (SCC) is a barometer of cow health and milk quality (Table 2). The U.S. requires that the SCC of individual producers be less than 7.50×10^5/mL, and the European Union (EU) has required raw milk SSC to be less than 4×10^5/mL since 1992. However, in China, the national standard for raw milk implemented in 2010 did not include any SCC limit requirement, and the first draft of the national standard for raw milk, published in 2020,

DOI 10.15302/J-SSCAE-2022.02.002

set the qualified level SCC limit at 1 × 10^6/mL, which lags significantly behind the requirements of Europe and the U.S. In terms of physical quality, light industrial products, electronic appliances, daily necessities, textiles, and other areas still encounter product quality problems. The results of the 2018 Chinese national supervision and sampling of product quality (Fig. 1) shows that the failure rate of the following products exceeded 5%, including 12 kinds of daily necessities and textiles, 13 kinds of electronic and electrical products, and four kinds of light industrial products. Among the many unqualified products, the quality of innovative products is particularly prominent.

Table 2. Comparison of microbial and somatic cell limit standards for raw milk.

Indicators	EU	US	Raw milk acquisition standard in 1986	National food safety standard for raw milk in 2010	National food safety standard for raw milk in 2020 (Draft for comments)
Total number of colonies (ten thousand CFU/mL)	≤10	≤50	Grade I ≤ 50 Grade II ≤ 100 Grade III ≤ 200 Grade IV ≤ 400	≤200	Excellent ≤ 10 Good grade ≤ 50 Qualified grade ≤ 100
Somatic cells (ten thousand /mL)	≤40	≤75	None	None	Excellent ≤ 40 Good grade ≤ 75 Qualified grade ≤ 100

Note: CFU refers to colony forming unit.

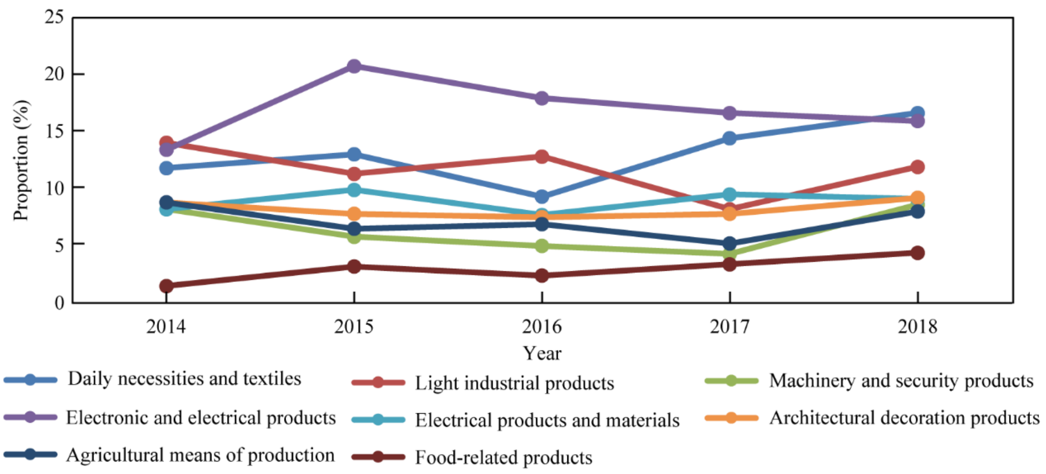

Fig. 1. Non conformity detection rate of seven major categories of products from 2014 to 2018

In terms of consumer evaluation, in 2020, Chinese market supervision authorities received a total of 6.93 × 10^6 complaints, 1.39 × 10^6 of which were due to problems with product quality, thus accounting for about 20.09% of all complaints. The number of reported quality problems grew quickly, up 202.70% year-on-year (data from the Department of Supervision and Management of Network Transactions, China General Administration of Market Supervision). Indeed, the perception of product quality has become a negative factor that affects the overall perception of Chinese brands. The National Manufacturing Index shows that China ranks 49th, with very low scores in some dimensions such as high quality and safety standards [25]. The results of the *2021 Global Survey on China's National Image* indicated that the main obstacle currently preventing overseas respondents from purchasing Chinese products is the fact that overseas consumers believe that the quality of Chinese products is not up to par.

3.4 Quality control transformation

The *Blue Book on Quality Control in Chinese Manufacturing Enterprises (2018)* reports [26] that, in terms of design quality, the percentage of enterprises that can continuously introduce new R&D quality control methods is only 19.6%, and the percentage of enterprises that use common R&D quality technology methods, such as fault tree analysis, quality function unfolding, and multi-factor analysis of variance in the R&D process, is less than 50%. In terms of precision control, 16% of the surveyed companies could use statistical process control and other quality tools to perform production process adjustment or improvement, and only 13.9% of the surveyed companies had established a complete process capability evaluation and management process for key processes. In terms of digital management, only 8.4% of enterprises had achieved 80%–100% automatic data collection, and most were still at the stage of over-collection from manual to automatic data collection. Therefore, there is still a long way to go before Chinese firms can successfully implement comprehensive and intelligent quality control. The digitalization of quality control in small- and medium-sized enterprises (SMEs) is especially backward; 54.59% of SMEs have not yet established quality control information systems, and only 11.07% of those that have established quality control information systems cover half of their quality operations [27].

4 Analysis of China's manufacturing product quality development problems

4.1 In the macro, quality strategy implementation is not enough

Many enterprises emphasize product innovation while ignoring product quality and equate quality improvement with product and technological innovation. In other words, they understand quality upgrading simply as eliminating traditional industries (e.g., textiles and garments) and developing new industries (e.g., photovoltaics and new energy). Low-level and repeat construction of a large number of projects according to traditional thinking cannot promote industrial upgrading and may cause overcapacity. In addition, selective discrimination policies against traditional industries have deprived them of opportunities to transform and upgrade their advanced manufacturing technologies. Developed countries, however, take advantage of the evolution of technology and cross-border integration to transform and upgrade traditional industries and seize future high points of industrial development. For example, with the help of revolutionary technological innovation, the U.S. textile industry is creating textiles and fabrics with previously unseen functions and high performance; for example, textiles and fabrics that can change colors, store energy, regulate temperature, monitor health, etc. Advanced manufacturing can utilize advanced technologies to develop new products and transform traditional ones, thus achieving high-quality manufacturing development.

Furthermore, the advantages of institutional mechanisms were not considered in terms of implementation. Strategy design is not comprehensive, and the national quality strategy has become a de facto sectoral strategy. Between government departments, sectoral interests and a lack of information have dispersed the power of the quality strategy. Under an innovation system dominated by research institutes, the separation of research institutes and enterprises leads to not only a serious disconnect between industry, academia, research, and use but also to a lack of practicality, effectiveness, and adaptability of quality resource inputs, as well as inefficient quality resource input mechanisms and use. Additionally, policy implementation lacks implementation and verification mechanisms; therefore, the quality strategy implementation effect is lower than expected.

4.2 In the micro, the main responsibility of enterprises to implement the difficulties

The fundamental problem lies in equating quality with meeting national standards. In attempts to strengthen quality control, government departments have determined the bottom-line standards that enterprises should comply with in terms of quality, safety, and environment from the perspective of products or processes. However, many enterprises treat compliance with the bottom-line standards as a quality development goal, leading to difficulties in achieving an exact match between the quality standards produced and users' needs. For example, all the steel coils of a certain steel company met the manufacturing standards in factory performance tests, but cracking occurred in the bulk during the stamping process. This is because the user improves the production process, the actual quality standard required increases, and the enterprise's original supply standard does not meet the requirements. Such a situation represent a typical mismatch of standards between the two sides, highlighting the quality problem of "standard incompatibility" [28].

Another issue is equating quality control with quality department work. Many companies treat quality as a matter for the quality control department and lack a comprehensive process that would result in a quality control mechanism and responsibility system within the company. The quality control department lacks the resources and ability to manage quality. A survey by the China Quality Association revealed that only 21.9% of the surveyed enterprises' quality control departments could organize and supervise other departments at the same level to implement quality requirements and quality control synergy between departments was insufficient.

Firms seek long-term advantages but find it difficult to give up short-term benefits. Quality improvement requires investment, including an increase in local process costs and even sacrificing part of the production upfront. However, it is difficult for business decision-makers to decide between short- and long-term benefits, leading to

DOI 10.15302/J-SSCAE-2022.02.002

work suffering from loss and gain and making substantial progress difficult. In the context of an incompletely competitive environment, enterprises are more willing to pursue short-term arbitrage rather than focusing on the long-term development of quality.

Local improvements cannot compensate for weak systems. Quality improvement is a systematic project. For example, steel manufacturing is a multivariable, lengthy procedure, and product quality is affected by each link and variable in the process. If quality control is implemented with a "fire-fighting" mentality, companies are often overwhelmed. Nevertheless, focusing only on local improvements and ignoring quality system construction is the current habit of most enterprises.

4.3 The ecological system lags behind

In terms of regulation, the quality of the legal environment needs to be optimized. The lack of a deterrent effect may impede investigations and crackdowns on counterfeiting and substandard products. Unqualified production capacity cannot be withdrawn from the market, squeezing out the development space for high-quality production capacity. The *2017 Situation Report on Counterfeiting and Piracy in the EU* pointed out that Chinese exports still face the outstanding problem of low quality. Meanwhile, there is insufficient willingness and strength to protect consumers' quality rights and interests, and consumers' role in promoting quality development is restricted. In addition to the insufficient legislation on consumer infringement, enforcement is too lax, which sometimes means that consumers' legitimate rights and interests are poorly protected.

In terms of policy, there are inadequate quality regulations for industrial and competitive policies. Public procurement does not provide sufficient leadership for quality development, and the role of quality in resource allocation is not reflected sufficiently. Government and defense procurement in the U.S. and EU are important policy tools. The U.S. Defense Procurement purchases goods from SMEs and provides high prices. In China, although government, defense, and state-owned enterprise procurement are pivotal in the allocation of social resources, the role of quality in resource allocation is neglected. SMEs do not invest sufficiently in quality, and there is a lack of core competitiveness. The U.S. federal government provides 50% of the funding for SMEs to receive relevant quality-based services to help them improve their product quality control. Nevertheless, China still lacks sufficient industrial, financial, and other policies that support quality development.

In terms of foundations, there is a lag in the layout of quality infrastructure and a mismatch between quality infrastructure capacity and high-quality industrial development. Furthermore, there is a lack of professionals and skills. Quality is an economic and technical characteristic at the macro and micro levels, respectively. Product quality improvement and industrial quality upgrading require the support of skilled personnel in all aspects, especially professionals for quality. While quality development depends on the technology, equipment, and quality synergy of SMEs in the industrial chain, it ultimately depends on the quantity and quality of people. Indeed, the root cause underlying China's inability to produce ultrahigh-precision products is the lack of both theory and practice of high-quality personnel. Additionally, Chinese enterprises generally have short lifespans and lack knowledge and skill accumulation.

5 International experiences in improving the quality of manufacturing products

5.1 Integrating and implementing the quality-related policies for the manufacturing industry

The U.S., Germany, Japan, South Korea, India, and other countries have implemented quality strategies and policies to enhance the competitiveness of manufacturing products. Some countries establish the positioning and benchmark of quality development according to resource endowment. In the competition for quality, each country often determines the direction of quality development and the goals to catch up to its own development needs. After World War II, Japan learned from the quality development experience of the U.S. and drew on German manufacturing ideas to form a set of manufacturing quality development models suitable for resource-poor countries. Since the 1990s, South Korea has been aiming at quality development to narrow the gap with Japan in the middle- and high-end fields, to form quality barriers to insulate itself from China in the low-end fields, and to become a "professional" manufacturing quality power in the fields of automobile manufacturing and electronic information. The EU has been developing high-quality and high-value-added manufacturing as the goal of quality development to maintain the social development needs of member countries with high wages and welfare. In 2014, India proposed the "Made in India" program with the goal of "zero defects, zero impact" quality development [29].

The implementation of quality in various industries can be promoted by making comprehensive use of policy tools. In the 1980s, the U.S. enacted the *National Quality Improvement Act* to improve quality and productivity, implemented the "Reliability and Maintainability 2000 Action Plan" (R&M2000) and the *Fastener Quality Act* in the in the defense and parts sectors, respectively, and implemented a "manufacturing expansion partnership" (MEP) for SMEs [30]. Since the 1990s, South Korea has continued to issue basic plans for quality control at the national level, focusing on the automotive and electronics industries at the industry level, launching the Single Quality Innovation Program (PPM) campaign, enacting the *Export Product Quality Promotion Act*, and implementing the XC-5 project, which focuses on improving automobile quality. In the second decade of the 21st century, the Quality Council of India responded to the "double zero" goal of "Make in India" by establishing and implementing the ZED ("double zero" certification) program to improve the quality development of SMEs. Focusing on the development of the aircraft manufacturing industry, Japan implemented the *Guidelines for Production Management and Quality Assurance in the Aircraft Components Industry* and the *Guidelines for Small- and Medium-Sized Enterprises to Enter the Aircraft Industry and Obtain International Certification* (NADCAP) to strengthen the quality foundation of the industry.

5.2 Promoting simultaneous planning and integrated construction of quality control, technological innovation, and industrial layout

Technological innovation, industrial policy, and quality control are often managed by different departments. However, their elements and links are closely connected.

Manufacturing processes and value chain management are considered in parallel with product and technological innovation processes. The future development of global manufacturing faces many new trends, including shorter product life cycles, increased complexity in design and manufacturing, higher customization requirements, and sustainability issues. Successfully addressing these issues is highly dependent on the production capacity of manufacturing systems. The European Future Factory Research Association is particularly concerned with the relationship between product and production process innovations throughout the lifecycle and works to ensure that manufacturing system capabilities follow product and material roadmaps to achieve viable and sustainable high-tech product manufacturing. In the short term, it establish a closed loop between product and production process innovations through a manufacturing-oriented design. It also anticipated a long-term technology roadmap for the product sector to align with the production technology roadmap. The US Additive Manufacturing Innovation Institute has included process and value chains in its technology areas and created roadmaps for the five most significant impact technology areas, advancing in parallel with design, materials, and other technologies [30].

The integration of measurements, standards, conformity assessment, and other elements in the process of product and technological innovation should be promoted. In the U.S., for example, the development of advanced manufacturing attaches great importance to industrial technology bases. In industrial development planning, an industrial technology base is planned to improve the quality of finished products in mass production, reduce end-to-end value chain costs, and shorten the time to market for new products.

5.3 Taking digital transformation as an entry point to promote the deep integration of quality control and Industry 4.0

As an important issue of digitalization, networking, and intelligent transformation of the manufacturing industry, the digital transformation of quality is receiving attention from developed countries.

Accordingly, it is imperative that we establish quality information linkages and share standards for smart manufacturing and supply chain quality control. Data play a central role in the era of smart and digital manufacturing. Creating, exchanging, and processing product design and manufacturing data and information are crucial for competitiveness. Quality is a key element in smart manufacturing, and the collection and flow of quality data are the foundation and prerequisites for achieving smart manufacturing and digital quality control. The American ANSI/QIF 2015 standard, which proposes the concept of a quality information framework (QIF), uses advanced technologies in smart manufacturing (e.g., Model-based definition, digital twin, and big data technologies) to solve the fundamental problems of manufacturing quality development and empower quality digitization. The QIF focuses on quality measurement (including information models for six different application areas), identifying common information elements from a system perspective, providing standardized infrastructure and technologies, building a data feedback mechanism for each link from design to measurement, and issuing standards and tools for achieving quality digitization in smart manufacturing. In Japan, the Ministry of Economy, Trade and Industry has clearly proposed promoting the sharing of quality data among industries as well as supply chains in its "*Measures to Strengthen Quality Assurance in Manufacturing*" [31]. Japan is currently promoting a

DOI 10.15302/J-SSCAE-2022.02.002

series of data-sharing standards. Meanwhile, in the European automotive industry, tire companies and upstream suppliers share data for the management of quality traceability.

Another key step is developing and popularizing new quality control techniques and tools for digital quality control. For example, EU-funded researchers are developing advanced manufacturing technologies aimed at achieving zero-defect production for everything from aircraft parts to machine tools. Examples include new quality monitoring tools, zero-defect intelligent measurement systems, advanced zero-defect manufacturing decision tools, self-learning systems, and a variety of other zero-defect technologies.

5.4 Creating a quality ecological environment to enhance the development of manufacturing product quality

Quality is the result of not only technological progress and management optimization but also an increased sense of responsibility. To activate the momentum of society in the pursuit of quality, it is necessary to create a high-quality ecological environment.

The first step is to establish a scientific evaluation system. For example, the U.S. has implemented a grading management model for dairy products, where different levels of milk sources are used for different products. Quality grading guides processing companies to differentiate the use of high-quality milk sources from general milk sources to drive the development of a quality dairy industry. At present, the China Iron and Steel Association has established mathematical models (e.g., process evaluation, quality genetics and value function) through big data of production line and prepared grading specifications, which have been promoted and applied in Sinopec, China National Offshore Oil Corporation, and the China Shipbuilding Industry. In January 2018, the first batches of three types of steel products—steel for containers, steel for the offshore industry, and steel for shipbuilding—and 22 production lines were ranked in terms of quality capability, thereby laying the foundation for exploring and establishing a grading system for steel product quality.

The second step is to allocate resources for quality. In the past, Germany, Japan and other countries have experienced a dilemma where production factors and economic structures shift from real to virtual, leading to significant economic damage. At present, Germany, Japan, and other manufacturing countries have maintained core positions in the entity economy. Only by optimizing the distribution system and resource allocation and truly forming an atmosphere of respect for quality and manufacturing in the whole society can the manufacturing industry better play the role of a “stabilizer” in the economic structure. In the process of promoting the ZED program in India, the Indian government rewards quality development behavior by providing direct financial support to participating SMEs as well as bank loans, defense, and government procurement opportunities.

6 Suggestions

6.1 Clarifying the strategic positioning of product quality development and strengthening the coherence of national quality policy

When formulating the national comprehensive and manufacturing special development plans, we should first clarify the strategic positioning and objectives of the development of manufacturing product quality while adhering to quality standards and maintaining the consistency of the national quality policy. In terms of target setting, we ought to strive to overcome a number of shortcomings in quality safety and reliability by 2025 and reach the level of a “professional” manufacturing quality in some key areas. By 2035, we will basically have solved the shortcomings of quality safety and reliability that restrict the high-quality development of the manufacturing industry and have significantly increased the added value of the industrial chain, with quality development approaching or reaching the level of a “comprehensive” manufacturing quality. In terms of strategy implementation, we recommend starting with two directions: quality excellence and quality conformity. In high-value-added and highly reliable fields, such as automobile manufacturing and CNC machine tools, we should continue to promote digital manufacturing and zero-defect manufacturing, focus on solving the problem of low reliability of equipment product quality, and strive to create products with excellent quality. For safety-sensitive, labor-intensive industries (e.g., textile and garments, food manufacturing), we should take the reshaping of quality and safety recognition as core objectives to promote automation, continuity, and intelligence in the production process, accelerate product innovation, improve product quality, and reduce production costs. We should re-engineer industrial quality infrastructure and enforce the standard requirements and implementations to solve the problem of domestic and foreign consumers’ lack of recognition of the quality of Chinese manufacturing.

6.2 Implementing the three pioneering action plans on manufacturing quality improvement while focusing on the future needs of industrial development

According to the needs of economic and social development to stabilize jobs and safeguard national defense and economic security, three pioneering action plans are proposed in a number of key areas. The first action plan pursues quality improvement in quality-competitive industries. The plan aims to focus on quality-competitive industries (e.g., automobiles), targeting the general trend of technological change and consumer upgrading. Specifically it centers on solving a number of shortcomings that limit the development of quality technical standards, production processes, quality control, after-sales services, and other issues to create a number of invisible champion enterprises with a global influence and quality-competitive industrial clusters. The second action plan aims to improve the quality of the equipment industry through a number of measures. First, it integrates advanced manufacturing technology, quality control technology, and supply chain quality control technology. Second, it explores the implementation of zero-defect manufacturing technology for products, processes, equipment, and processes. Third, it improves the quality of equipment product manufacturing, reduces waste of manufacturing resources, and shortens the manufacturing cycle in aerospace, CNC machine tools, and other high value-added areas. The third action plan aims to improve the quality of export products. Taking the export destination as traction and mechanical and electrical products, textile and garment products, and other large-volume products as carriers, it initiates quality improvement actions to form new competitive advantages in terms of quality, standards, and whole life cycle economics by targeting the quality needs of products exported to the EU, Southeast Asia, Africa, and other regions.

6.3 Taking digital transformation as traction to accelerate the innovation of the theories, technologies, and tools of quality control

With the development of Industry 4.0, we should follow the development trends of digitalization, networking, and intelligence in the manufacturing industry and focus on promoting synchronous innovation and deep integration of quality control. On one hand, we should strengthen research on the impact of the Fourth Industrial Revolution on product quality strategy and quality control. It is important to determine the effects of the new round of technological revolution and industrial change on quality supply and demand and changes in production and consumption patterns on the change of quality control theory, technology, and tools. To that end, we ought to research the continuous impact of product customization, production digitalization, and value service transformation on quality control strategies, tasks, and methods. Meanwhile, we should focus on promoting technological innovation in key areas by gleaning foresights into quality technology and rolling out a roadmap for quality technology evolution in the areas of digital quality control, zero-defect quality control, quality reliability engineering, and supply chain quality control in response to future manufacturing development needs. We should promote innovation in measurement foundations, software platforms, data standards, and auxiliary decision-making tools required for digital quality control. Additionally, we should encourage innovative practices in intelligent quality control and focus on solving key technologies, such as quality monitoring, intelligent measurement, autonomous decision-making, and digital threading. Finally, we should focus on supply chain quality assurance capacity building, conduct research on network information and sensor technology, and explore big data integration applications for quality.

6.4 Integrating the development of industrial quality infrastructure to consolidate the cornerstone of manufacturing product quality improvement

We should integrate the development of industrial quality infrastructure and focus on solving the problem of technological innovation and industrial development from “nothing to something” and from “something to something excellent.” At the system level, we ought to clarify the objectives and tasks of industrial quality infrastructure at different stages of industrial development. In the initial stage, we should plan the layout of industrial quality with high standards and identify starting points to prevent innovative industries from falling into a trap of low-quality development and overcapacity. At the stage of industrial-scale development, we should provide measurement, standard, testing, and certification support to ensure the quality of mass production, shorten the product launch cycle, reduce end-to-end industry chain costs, and enhance market quality recognition. At the technical level, we should center the technical support capacity around the development requirements of strategic emerging industries and high-tech manufacturing industries and build a number of national industrial quality infrastructure laboratories. We recommend adjusting and optimizing industrial quality infrastructure resource

DOI 10.15302/J-SSCAE-2022.02.002

allocation and innovation capacity construction to meet the requirements of regional coordinated development strategies, such as the development of Greater Bay Area and the coordinated development of Beijing–Tianjin–Hebei and to form a reasonable, strong, fair, and credible industrial quality infrastructure service system. We should conduct research on common technology mapping of metrology, standards, testing, and certification and develop a directory of key common technologies for the development of industrial quality infrastructure innovation. Lastly, we should establish and improve industrial quality infrastructure planning, construction, service effectiveness assessment, and evaluation mechanisms and conduct stage, project, and social evaluations.

6.5 Promote the recycling of the quality ecological environment to improve enterprises' willingness to improve product quality

In terms of market supervision, we should strengthen the supervision of unqualified enterprises and the governance of industry-wide quality problems and promote the clearance of unqualified production capacity. We should strictly protect consumers and increase punishment compensation so that enterprises cannot, or will not produce counterfeit, substandard products. In terms of resource allocation, we should establish a quality grading and support policy system to better convey quality information and provide a basis for consumer choice and market competition. We should vigorously implement a "higher quality, higher price" concept, and optimize resource allocation so that enterprises are willing to invest in quality. In terms of talent training, we should, in the short term, focus on establishing a green channel for the introduction of "high-precision" technology and technical personnel and introduce a number of senior skilled workers. In the long term, we should focus on training skilled workers to provide support for the construction of a country that can be recognized for its strong manufacturing quality. In terms of institutional mechanisms, we should focus on the actual needs of industrial innovation and quality development and establish a policy synergy mechanism among innovation, industry, quality, finance, education, and other sectors to enhance the integrity and coordination of quality policies and improve their effectiveness.

6.6 Exploiting the advantages of the system and mechanism to implement the basic project of improving the quality of manufacturing products

In accordance with the spirit of the fifth meeting of the Central Committee for Financial and Economic Affairs, which called for the development of the manufacturing industry to give full play to the advantages of the system of concentrated efforts to do great things and the advantages of the market on a large scale and to consolidate the basic capabilities of the industry as a fundamental, we should draw up the "14th Five-Year Plan" for manufacturing product quality development, implement several key projects, and solve a number of key quality shortcomings. We should implement world-class high-quality brand high-end projects, consider several industries with competitive advantages as carriers, and encourage and guide industrial enterprises to consistently use the Internet and big data. Based on consumer demand, quality and safety traceability, and visualization management in product design, manufacturing, sales, and service, standards, conformity assessment, and market supervision should be strengthened. Additionally, consumers should recognize the quality and safety of traditional products, and the quality influence of the Made in China brand should be improved. We should implement projects that seek to build strong foundations for quality in emerging industries; focus on the prevalent specific issues of consistency, reliability, safety, and manufacturing maturity in the process of industrialization in the areas of artificial intelligence, additive manufacturing, and self-driving cars; and tackle technological problems to improve the overall quality assurance capability of the industry chain in emerging industries. We should establish several quality common technology platforms to provide specialized solutions to the key common technology problems innovative enterprises face. We should also implement a digital quality control empowerment project to guide enterprises to compensate for the shortcomings of lean quality control. Finally, we should lend strong support to leading quality enterprises carrying out digital quality control innovation in product design, product manufacturing, supply chain management, and other aspects to form a set of theoretical, standard, technical, and tool systems that are suitable for the development characteristics of Chinese manufacturing enterprises.

References

[1] Linder S B. An essay on trade and transformation [M]. Stockholm: Almqvist & Wiksell, 1961.

[2] Schott P.K. Across-Product Versus Within-Product Specialization in International Trade [J]. Quarterly Journal of Economics, 2004, 199(2): 647-678.
[3] Amiti M., Khandelwal A. Import Competition and Quality Upgrading [J]. The Review of Economics and Statistics, 2013, 95(2): 476-490.
[4] Bernard A. B., Jensen J. B., Schott P. K. Trade Costs, Firms and Productivity [J]. Journal of Monetary Economics, 2006, 53(5): 917-937.
[5] Kugler M., Verhoogen E. The Quality-complementarity Hypothesis: Theory and Evident from Colombia[R]. Cambridge: NBER Working Paper, 2005.
[6] Kuger M., Verhoogen E. Prices, Plant Size, and Product Quality [J]. Review of Economic Studies, 2012, 79(1) :307-339.
[7] Fan H., Yao A. L., Yeaple S. R. Trade Liberalization, Quality, and Export Prices [J]. Review of Economics and Sta-tistics, 2015, 97(5): 1033-1051.
[8] Yu M J, Li L R. Trade liberalization and quality upgrading of imported intermediate products: evidence from the product level of China's customs [J] Economics (quarterly), 2015, (4): 1011-1028. Chinese.
[9] Wang X J. Trade liberalization, quality gap and quality upgrading of regional export products [J] International trade issues, 2014, (10): 131-142. Chinese.
[10] Xu J Y, Mao Q L, Hu Angang. Import of intermediate products and quality upgrading of export products of enterprises: a study based on Chinese evidence [J] World economy, 2017 (3): 52-75. Chinese.
[11] Shi B Z, Shao W B. Measurement of export product quality of Chinese enterprises and its determinants: a micro perspective of cultivating new export competitive advantages [J] Management world, 2014, (9): 90-106. Chinese.
[12] Zhang J, Zhai F X, Zhou X Y. Government subsidies, market competition and export product quality [J] Research on quantitative economy and technical economy, 2015, (4): 71-87. Chinese.
[13] Fan H C, Guo G Y. The relationship between export price, export quality and productivity: evidence from China [J] World economy, 2015, (2): 58-85. Chinese.
[14] Zhang J, Zheng W P, Zhai F X. Has the quality of China's export products been improved [J] Economic research, 2014, (10): 46-59. Chinese.
[15] Shi B Z, Wang Y X, Li K W. Quality measurement of China's export products and its determinants [J] World economy, 2013, (9): 69-93. Chinese.
[16] Xu J Y, Tong J D, Mao Q L. RMB exchange rate, product quality and enterprise export behavior -- an empirical study at the level of Chinese manufacturing enterprises [J] Financial research, 2015, (3): 1-17. Chinese.
[17] Guo K S, Tian X X. Accelerate the construction of a new development pattern and the transformation and upgrading path of manufacturing industry [J] China industrial economy, 2021 (11): 44-5. Chinese.
[18] Cai F. Productivity, new kinetic energy and manufacturing -- how to improve the efficiency of resource reallocation in China's economy [J] China industrial economy, 2021 (05): 5-18. Chinese.
[19] Feenstra R C, Romalis J. International prices and endogenous quality [J]. The Quarterly Journal of Economics, 2014, 129(2): 477-527.
[20] Lv T, Liu D. High quality development of manufacturing industry: gaps, problems and measures [J] Learning and exploration, 2019 (1): 7. Chinese.
[21] World managers Overseas buyers "see" the globalization of Chinese brands - 2018 overseas buyers Research Report [EB / OL] （2018-08-01）. https://new.qq.com/omn/20180914/20180914A1EY8V.html. Chinese.
[22] Reference message network US media said that the manufacturing industry will return to the U.S.: China has lost its labor advantage [EB/OL]（2016-08-28）. http://www.cankaoxiaoxi.com/finance/20160828/1284001.html. Chinese.
[23] Xinhua CCID robot 3 • 15 report reveals six pain points in product quality [EB / OL] （2018-03-14）. http://www.xinhuanet.com/tech/2018-03/14/c_1122538434.html. Chinese.
[24] Li Xiaoxin Product quality problems will induce the crisis of photovoltaic industry exhibition [R] Beijing: CCID think tank, 2015, issue 20. Chinese.
[25] Ahlswede Thomas, Statista made-in-country index（MICI）2017——A global comparison of country brands [D], Paderborn: University of Paderborn, 2017.
[26] China Quality Association Blue book on quality control of Chinese manufacturing enterprises (2018) [M] Beijing: People's publishing house, 2019. Chinese.
[27] Guo Z, Zhu Q Q. Investigation report on the quality status of small and medium-sized enterprises in Shanghai in 2018 (Part 2) [J] Shanghai quality, 2019 (4): 5. Chinese.
[28] Sun J X, Chen C, Fu Q, Ji D P, Shi G J. How to have both fish and bear's paw -- looking for a good recipe for quality control of iron and steel products [R] Shanghai: McKinsey consulting, 2019. Chinese.
[29] Sang M Lee. The age of quality innovation [J].International Journal of Quality Innovation，2015, (5): 1-5.
[30] China Electronic Information Industry Development Research Institute Interpretation of American Institute of manufacturing innovation [M] Beijing: Electronic Industry Press, 2018. Chinese.
[31] Ministry of economy and industry of Japan Japanese manufacturing white paper (2018 Edition) [R] Beijing: Industrial 4.0 Research Institute, 2018. Chinese.