

**Nodira B.
Abdusalomova¹**
Tatiana N. Litvinova
Anastasia A. Kurilova
Larisa V. Shabaltina

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PRODUCT QUALITY MANAGEMENT IN THE DIGITAL ECONOMY MARKETS: MONITORING OF INTERNATIONAL EXPERIENCE AND PERSPECTIVE FOR IMPROVEMENT

Abstract: *Product quality is the basis for demand at national and world industry markets and a precondition for the competitiveness of manufacturing companies. Modern conditions, predetermined by the insufficient volume of resources, problems with personal provision, and high requirements for physical, chemical, environmental, and exploitation indicators of products involve the focus on the capabilities of the digital economy. Digital economy markets offer a rather wide range of tools that allow solving various tasks faced by manufacturers in the sphere of management and improvement of the level of product quality.*

This research proved the hypothesis on the direct dependence between digitalisation and achievement of effectiveness in ensuring the main indicators of product quality in companies from various spheres of the economy. The scientific novelty of this research is due to the substantiation of the features of implementing innovative directions for product quality management with the use of digital tools in countries with various economic systems.

Keywords: *product quality management, digital economy markets, monitoring, international experience, prospects for improvement, cybernetic production systems, network integration*

1. Introduction

Competition of world manufacturers of products in digital economy markets requires an advantage by consumer indicators, the price/quality indicator, and the indicator of quality. Modern technologies allow manufacturing more functional products. Achievement of product quality is the key possibility for successful international integration of the manufacturer, brand, and country in the given sphere. Certain countries are world leaders in the

manufacture of certain types of products, and the formation of the digital economy allowed them to improve their capabilities or, given the absence of the appropriate technologies, resources, and financial support, ensuring higher quality and achievement of price/quality ratio. Other countries, despite the quick industrial growth, were not able to implement a quick transition to the information society and digital economy and implement modern technologies in sectors that manufacture mass products for world markets. These countries include China and

¹ Corresponding author: Nodira B. Abdusalomova
Email: abdusalomova2016@mail.ru

India, which, in the past, had a focus primarily on the agrarian sector and industrial production with low value-added. In the early 21st century, these countries began implementing digital technologies and raised product quality, which influenced its value-added. Economically developed countries combined traditional experience of product quality management and used approaches to digitalisation of production to become world leaders in certain spheres and improve their positions.

Experience of world-leading companies in product quality management in digital economy markets can allow overcoming difficulties in this sphere in countries with low GDP and problems with resources. Growth of product quality becomes its competitive advantage, which automatically facilitates assigning to the category of products with high value-added. Accordingly, growth of quality allows for an increase in revenues from product sales (including exports), which will ensure the growth of citizens' well-being and competitiveness of the sector, as well as an increase in the countries' position in digital economy markets.

The research hypothesis is connected with the confirmation (or disproval) of the assumption of the positive influence of the growth of the use of digital economy tools on the growth of product quality.

The goal of this paper was to analyse the directions of international experience and prospects for improvement of product quality management in digital economy markets. For this, the following tasks were solved: determining the most adaptive directions of the experience of product quality management in digital economy markets; considering the prospects for implementation of this experience in countries that need to improve product quality management to satisfy domestic needs and raise the exports due to the growth of value-added.

2. Materials and method

There are many works devoted to the issue of product quality management in digital economy markets. Elg et al. (2021) dwelt on the features of approaches to product quality management in the conditions of digital technologies implementation in Sweden and the problems caused by the transition to ICT. Filz et al. (2023) and Paunovic et al. (2023) considered the specifics of implementing the direction of high-tech product quality management that is based on the use of cybernetic production systems. Kafel (2023) studied the connection between the logistics and implementation of approaches to product quality management; the results of this work allowed considering the possibility of integrating logistics and production into one system of assessment. Nguyen et al. (2024) presented an evaluation of the use of the direction of product quality management that is based on the strategy of network integration of the market environment participants. Al-Worafi (2020) presented a list of qualitative indicators of the safety of pharmaceutical products, which is used during their evaluation by the examples of the leading countries in this sphere. Jadaun et al. (2023) aimed to study the approach to managing the quality of pharmaceutical products in India, which level allowed the country to become one of the leaders in this market. Golubchik (2023) formulated directions for quality management with a focus on the achievement of consumers' expectations and consideration of their interests as to certain components in this sphere. De Sales et al. (2022) proved the influence of the creation of innovative products on the continuous support for product quality. Uddin (2020) presented theoretical aspects of the determination of product quality indicators, which are necessary for further analysis of their correspondence.

The large number of scientific works on the considered topic is a sign of the importance of the problem of dependence of product quality management on the level of digitalisation, which, at the current stage of formation of society and economy, defines the capabilities of companies, sectors of the economy, and the level of country's competitiveness in certain spheres. A relevant problem is the identification of the key directions in management and improvement of product quality management in the conditions of the use of digital tools.

This research was conducted with the help of a range of general theoretical and special methods. The method of unification was used to determine the provisions of approaches and directions for product quality management in the conditions of the digital economy, revealed based on the assessment and analysis of the authors' positions and research materials. Comparative analysis allowed us to reveal the features of the directions for quality management in the digital environment. The statistical method enabled us to determine the factual data on the implementation of approaches to management in the considered sphere in the considered countries.

3. Results

Let us consider the monitoring and systematisation of the main directions of the international experience of product quality management in digital economy markets.

An important aspect of product quality management in digital economy markets is the contextual flexibility and continuity of the increase in research and experimental practices. In this case, it is the focus on the trend for striving towards the achievement of the Sustainable Development Goals in connection with the estimated indicators of the production process and products' characteristics. The focus on the flexibility

of research and experimental practice involves a clever combination of the level of research and approbation of the new (or existing) product to determine and/or create a new product. Continuity is connected with the fact that constant improvement of product quality is necessary for confirming competitiveness and correspondence to existing or changing standards. According to Elg et al. (2021), such an approach is called contextual ambidexterity, which involves flexible, timely, and constant support for two directions (research and experimental practices).

Let us consider the experience of India in the management of the quality of products of the pharmaceutical industry in the conditions of the digital economy.

The indicators of pharmaceutical products' quality are safety, which defines the absence of negative influence on the health of people and animals; effectiveness (achievement of the declared effect of treatment); price/quality ratio; sustainability (reduction of the level of testing medicines on animals) (Jadaun et al., 2023; Al-Worafi, 2020). India works on the implementation of contextual flexibility and continuity of the sustainable increase in research and experimental practices in the management of pharmaceutical product quality (Table 1).

As shown in Table 1, the innovative approach to product quality management with the use of ICT, which is implemented within the direction of contextual flexibility and continuity of stable increase in research and experimental practices, allowed the country to raise effectiveness in this sphere. Economic, market and quality indicators were achieved. The described tools of the digital economy allowed improving the effectiveness of the formation of national leading companies and the sector of the economy on the whole (pharmaceutical sector).

Table 1. Specifics of product quality management with the use of digitalisation and its results for the pharmaceutical industry of India

	Indicator	Description of the indicator
1	Product quality management in the pharmaceutical industry	<p>The use of periodic updating of The Indian Pharmacopoeia, which presents standards and norms set to all categories and types of products of this sector. The recent edition of 2022 determines a new approach to the system of product quality management of the pharmaceutical industry, which is based on 3R principles:</p> <ul style="list-style-type: none"> - Replacement of the use of living organisms in testing with an artificially created environment. Implementation of these principles is connected with the mass digitalisation in the management of the experimental part and the use of modelling of the results of the effectiveness of the impact of medicines and assessment of side effects; - Maximum reduction of the level of the use of experiments with the use of animals; application of high ethical standards when it is impossible not to use animals. Focus on the achievement of the minimum possible level of experiments in this category.; - Improvement of tests that are used in experimental research (implementation of wider testing ensured by innovative indicators, which are analysed with the help of innovative technologies). <p>The promotion of a new approach to quality management is connected with the declaration of these principles of safety of the experimental and research part of the development and implementation of products at the level of the main companies that manufacture pharmaceutical products.</p>
2	Influence on consumer expectations as to product quality	Adoption of the approach of the public, acknowledgement of the influence of the impact of ICT on quality
3	Market result	<p>Revenues from sales of pharmaceutical products of all categories in the world: 2005 – 601 billion USD, 2010 – 888 billion USD, 2014 – 1,064 billion USD, 2018 – 1,214 billion USD, 2022 – 1,482 billion USD, and 2023 – 1,607 billion USD.</p> <p>Revenues from sales of pharmaceutical products in India: 2005 – 25 billion USD, 2010 – 10 billion USD, 2014 – 12.5 billion USD, 2018 – 17.27 billion USD, 2022 – 48.4 billion USD, 2023 – 49.8 billion USD.</p> <p>2007 saw a crisis in the Indian pharmaceutical market. An additional negative factor was accusations of the international community regarding counterfeiting. The inspection showed the absence of counterfeit products. The crisis negatively influenced the production volumes and exports. The sector began recovery after 2010. The share of India’s market of pharmaceutical products: 2005 – 4.1 %, 2010 – 1.1 %, 2014 – 1.1 %, 2018 – 1.4 %, 2022 – 3 %, and 2023 – 3 %. The share of India’s market of pharmaceutical products India started growing after the implementation of new approaches to quality management and the focus on digital technologies in R&D.</p>
4	The economic result of implementing the innovative approach to quality management	<p>The use of the new approach since 2022 allowed raising sales revenues. Revenues: 2022 – 11.1 billion USD, 2023 – 11.8 billion USD, forecast for 2024 – 12.5 billion USD, forecast for 2028 – 15.9 billion USD.</p>

Source: Compiled by the authors based on (Agrawal, 2023; Anand, 2023; Avhad, 2020; Jadaun et al., 2023; Dwivedi, 2023; Statista, 2024a; Statista, 2024b)

A current direction of product quality management in digital economy markets is supporting and raising the level of achievement of standards and norms with the use of cybernetic production systems. This is connected with the support for a closed cycle

of monitoring of product quality in the following components: 1) production system; 2) collection and analysis of data on transformations of materials, resources, components, and energy into the unity of final products at different stages of the

production process (the use of digital monitoring, which involves the application of sensors, videocameras to detect defects, etc.; robots at production lines and lines of quality control); 3) cybernetic assessment of obtained data, systematised by categories, types, and levels of the complexity of defect and errors; 4) generation of the most optimal solutions for each unit of products with defects (modelling of possible managerial solutions with the following options: complete disposal (processing) of products with defects; improvement of separate elements and repeated control; implementation of changes in the technological changes to eliminate the possibilities of emergence of defects; replacement of materials and components with more optimal variants and analogues of higher quality and lower sensitivity to technological processes used at production,

etc.) (Filz et al., 2023).

The study of production systems allowed determining that at the modern stage, there is a trend for the application of the given direction in various sectors. It is rather widespread in the electronic industry. Electronic devices (smartphones, tablets, laptops, PCs, gadgets for a smart home, electric vehicles, space equipment, equipment in the sphere of security, intellectual systems for object management, etc.) – this is an inseparable part of the life of modern society and economy. Thus, we shall consider the implementation of this approach to product quality management by the example of the production of printed circuit boards.

According to Pcbonline (2023), there were 10 world leaders in the sphere of production of printed circuit boards at the end of 2023 (Table 2).

Table 2. Indicators of product quality management with the use of cybernetic production systems by the example of the leading countries.

Indicator	Description
1 Management of the quality of circuit boards	<p>There are unified standards of the quality of circuit boards: adaptability to various types of electronic products; eco-friendliness (low influence on the environment during utilisation, the possibility of disposal, production based on biodegradable materials; water absorption); durability (or correspondence to the declared term of exploitation); physical qualities.</p> <p>World-leading companies in the sphere of production of circuit boards focus on the implementation of cybernetic production systems. This direction of quality management requires investments in the purchase (or development) of cybernetic production systems, their adaptation to the specifics and potential of placement and organisation of production; the presence of trained personnel who can organise the work of these systems at the level of production and management of digital management, data analysis, and forecasting of decisions for the generations of the most optimal solutions; strategic focus of manufacturing companies on the constant reconsideration of the level of quality and correspondence of products to similar indicators demonstrated by rivals in the market.</p> <p>Mass implementation of cybernetic production systems in the production of circuit boards started in 2019-2020. Until that, only certain digital technologies were used, which ensured the achievement of the processes of production quality control.</p>
2 Influence on consumer priorities in the sphere of quality and the main indicators of circuit boards	<p>Implementation of the new direction of product quality management of printed circuit boards allows ensuring their use in high-tech spheres (space industry, security and defence, medical sphere (complex surgeries, diagnostics, etc.).</p>
3 Economic and market result	<p>The world market of printed circuit boards grows, ensuring the growth of production and sales of electronic industry products.</p> <p>Revenues from sales of printed circuit boards of all categories in the world: 2020 –</p>

	<p>65.1 billion USD, 2021 – 80.9 billion USD, 2022 – 87.9 billion USD, forecast for 2026 – 101.6 billion USD, forecast for 2029 – 119.1 billion USD.</p> <p>Cybernetic production systems allow reaching production growth and an increase in sales of the products of this category at the global level and the level of manufacturing companies.</p> <p>Structure of the leading regions in the production of printed circuit boards:</p> <ul style="list-style-type: none"> - Countries of Asia (apart from Japan and China) (primarily South Korea and Taiwan) – 29.9 % of the world market. The leading companies in the production of circuit boards are as follows: <ol style="list-style-type: none"> 1) Daeduck Electronics Co. Ltd. (South Korea). The company manufactures all types of these products, with modifications aimed at mass consumers. Advantages: the possibility of using the products in production and repairs of a large range of electronic industry products. Drawbacks: high price compared to analogue products from rivals; problems with timely delivery of products, insufficient level of service; 2) Unimicron Technology Corp. (Taiwan) (production of all types of printed circuit boards, focusing on mass consumption). Advantages: quality, which is confirmed by consumers' feedback; moderate price, which facilitates the growth of the volume of activities. Disadvantages: cooperation with large companies, which is a barrier to transition to the interaction with various categories of customers); 3) Tripod Technology Corp. (Taiwan) (production of flexible printed circuit boards, printed circuit boards of the HDI category (higher density, better innovative technologies in production). Advantages: moderate prices; aim at the use of the products in mass production of electronics. Disadvantages: wholesale production only; 4) Zhen Ding Technology (Taiwan) (production of all possible types and configurations of products). Advantages: high quality, which is confirmed by independent evaluations; the possibility of using in mass production of electronic industry products. Disadvantages: high price that leads to customers' preferring cheaper analogues; focus on wholesale production; - Countries of the EU (Italy, Austria) – 2.5 %. The leaders are as follows: <ol style="list-style-type: none"> 1) Italian Cisel (production of prototypes of printed circuit boards, rigid-flex and flexible printed circuit boards, and simple printed circuit boards). Advantages: an innovative form that allows using printed boards in devices that require compact components. Disadvantages: high price compared to rivals' products; limited production capacities, which does not allow for a quick increase in production volumes; absence of quick adaptation to innovations in technologies; slow delivery; 2) Austrian AT&S. Advantages: high quality, which is based on innovative types of cybernetic production systems, which are constantly improved. Disadvantages: high prices (which is a problem for customers from the EU); slow and disrupted logistics which influences the speed of product deliveries; - countries of Northern America (mainly USA) – 4 %. Market leaders: <ol style="list-style-type: none"> 1) Advanced Circuits (production of prototypes of printed circuit boards and all types of modern printed circuit boards). Advantages: quality, which is confirmed by stable demand in the USA. Disadvantages: relatively high price, product delivery terms; 2) TTM Technologies Inc. (production of all types and configurations of printed circuit boards). Advantages: high technological capabilities that satisfy consumers' needs; manufacture of products used in aerospace and defence industries. Disadvantages: focus on wholesale deliveries; high price, slow delivery. - Japan – 9 %. Market leader: NOK Corporation (manufacturer of flexible printed circuit boards). Advantages: quality, which is confirmed by experts and customers. Disadvantages: relatively high price; - China – 54.6 %. Market leader: Pconline (production of prototypes of printed circuit boards and all types of innovative printed circuit boards). Advantages: quality and price; high technological capabilities for the manufacture of innovative products. Disadvantages: complexities with translation of technical requirements from the Chinese language.
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Source: Compiled by the authors based on (Lee, 2024; LinkedIn, 2023; Olinapcb (2021)

The presented results of the research (Table 2) showed that cybernetic production systems allowed ensuring the growth of the quality of printed circuit boards in the world. The main world leaders in the manufacture of these types of products made an almost simultaneous transition to the application of this direction of digital support for quality management. This was predetermined by clear technological, environmental, and economic expectations of market consumers. Quality support in the production of printed circuit boards requires large investments in technological support for the complex of cybernetic production systems. That is why leadership in this sphere belongs to developed countries (countries of the EU, the USA, Japan, South Korea, and Taiwan) and quickly developing China.

The focus on the considered direction for quality management of products with the use of cybernetic production systems is used in other sectors of the economy, including the ones closely connected with the considered electronic industry.

It is also necessary to distinguish the direction of product quality management in the conditions of digitalisation that are connected with the use of the strategy of network integration of the market environment's participants. This ensures the synergy of interaction effects. Partners combine their efforts within this direction: manufacturers (the key link) of the main type of products; manufacturers of raw materials and works (services) that are used for the main production); companies ensuring logistics; organisations that deal with R&D; financial intermediaries that ensure financing of the production and logistics processes (Nguyen et al., 2024). Within this direction, the organisation of the interaction of the subjects of the sector of small, medium, and micro companies (including individual entrepreneurs) is ensured. Such types of partnerships are used in developed and developing countries. It is most important for

the latter, due to the difficulties with access to financing, resources, and technologies for certain participants.

Using this strategy, Vietnam was able to perform a transformative transition from an agrarian to an industrial economy, using a systemic reform over 2000 – 2019. As of now, the country continues to strengthen its position in international markets (Nguyen et al., 2024). Though even before 2000, products of the industrial sector dominated the national GDP, it was not very competitive and did not ensure high value-added. The main export articles were oil and products of the agrarian sector. Another feature of the Vietnamese economy is that before the reforms (2000), less than 14% of labour resources were involved in the industrial sector, while in 2022 – 21% (Statista, 2023). Despite certain transformations, the dominating part of labour resources was involved in agriculture in 2022, though the shift in the directions for employment is a sign of structural changes in the national economy in favour of the manufacture of products with higher value-added. This transition was predetermined by reforms and mass implementation of the network integration among the subjects of logistical, scientific & technical, financial, and production spheres that belong to the sector of small, medium, and micro companies. Among all subjects of this category, the industrial sector (as of year-end 2019) accounted for 31.6 % of companies (Economica Vietnam, 2021). The share of GDP from the sales of products by small, medium, and micro companies in Vietnam is growing. Analysis of the statistical data on Vietnam (Thuy, 2021) shows that this category provides 33% of GDP revenues from the industrial sector sales.

Let us consider the features and results of implementing the given approach to product quality management at the level of this category of companies (Table 3).

Table 3. Characteristics and results of implementing the approach to the management of the quality of products manufactured by small, medium, and micro companies of Vietnam in the conditions of the digital economy

	Indicator	Description
1	Specifics of product quality management	<p>Small, medium, and micro companies, which unify into networks to create unions that ensure the realization of the full cycle of financing, development, production, logistics, and sales of products, focus on high value-added of products. Such a category of products has innovative characteristics and high quality.</p> <p>Logistics, including timely delivery of resources and materials and delivery of products to storage and consumers, ensures product quality at the stage of the life cycle that follows the production stage.</p> <p>General requirements for the management of the quality of products that are exported for small, medium, and micro companies are as follows:</p> <ul style="list-style-type: none"> - Meeting sectorial requirements for product quality; - Marking and certification of products. <p>This category of companies does not face a requirement to check product quality at the company by a special control committee. Thus, small, medium, and microcompanies have certain advantages in the sphere of prevention of bureaucratic burden on quality control. Growth of quality, ensured by the implementation of this strategy, was observed in 2000 – 2019.</p>
2	Influence on consumer demand in the sphere of product quality	<p>An increase in product quality due to the implementation of the network integration strategy allowed ensuring the growth of demand in the world market for such categories of products manufactured in Vietnam: footwear, clothing, wood products, transport vehicles spare parts, and fish products.</p>
3	Economic and market results	<p>In 2022, the volume of commodity exports by Vietnam grew (in cost value) by 9.5%, compared to 2021, equalling 274.03 billion USD.</p> <p>The main categories of products exported by Vietnam to the world markets are as follows:</p> <ul style="list-style-type: none"> - Videocameras, photcameras, and accessories; - Steel and iron; - Fish products and seafood; - Transport vehicles and spare parts; - Wood products and timber (small, medium, and micro companies); - Footwear (small, medium, and micro companies); - Clothing (small, medium, and micro companies); - Equipment and machinery (large manufacturers); - Electronics and computers (large companies); - Smartphones and accessories (large companies). <p>Specialisation and focus on innovative digital technologies of quality management allow small, medium, and micro companies to achieve high results in the context of supporting and raising demand for products in the world markets.</p> <p>The tools of the digital economy that are used within the implementation of this strategy are as follows:</p> <ul style="list-style-type: none"> - Digital controllers of correspondence of the parameters of products at different stages of production and logistics; - Intellectual systems that are the basis for digital controller management. These systems were created with the use of AI technologies (machine learning, data collection and analysis, etc.); - Robotised equipment.

Source: Compiled by the authors based on (Dat, 2022; Nguyen et al., 2024; Tradeimex, 2023)

4. Discussion

Generalising the systematised directions of product quality management in digital economy markets, let us attempt to

determine the prospects for implementing the considered experience to improve this process.

Each of the three distinguished directions can be adapted to the conditions of

reformation of the quality management system with the use of digitalisation in developed and developing countries. An example is the implementation of each of them in developing countries (India, China, and Vietnam), while the possibility of implementing the second direction in developed countries is shown by the example of the EU countries, Japan, South Korea, and the USA. Thus, these directions could be adapted to various types of economic development.

Evaluation of the presented results of the research allowed formulating a range of the criteria for implementing the described optimisation directions, the support of which can create conditions facilitating effectiveness. These include the following:

- 1) 1st direction: strategic focus of manufacturing companies on an increase in the level of consumer expectations (also regarding the indicators of quality); availability of experimental and research digital platforms that are equal by capacities; support for the level of flexible reaction to the revealed problems of construction, configuration of products, and quality of raw materials;
- 2) 2nd direction: financial and personnel support, which allows implementing and managing cybernetic production systems; readiness for possible transformations of these systems according to new requirements in the sphere of quality management (qualitative and quantitative criteria of assessment);
- 3) 3rd direction: commitment to supporting world standards and norms of quality, even if they are much higher than national ones (due to the focus on the provision of integration in the international industry markets); adoption of the

focus on the achievement of certain high parameters of quality by all participants of the union that uses the network integration strategy; planned expenditures for innovations and constant quality control.

5. Conclusion

It is possible to state that the described directions for product quality management are relevant to the modern state of the digital economy. Their characteristics and features may change given the changes in the tools of digitalisation or the emergence of innovations in this sphere. Vice versa, stagnation can regulate the possibilities of raising product quality. Leading companies in innovations in the sphere of an increase in the indicators of product quality at the level of various sectors can create new modifications of quality standards, which will be supported by consumers. Accordingly, this will influence the development of markets under the influence of their participants, not the government.

The above aspects of quality management do not involve a strict approach to the regulation of a set of digital tools. Their combinations may vary depending on standards and norms set at the industry level and parameters of quality that are peculiar to the countries to which the products are exported. A rather important indicator of a positive image in the sphere of product quality management is supporting its equal level for various categories of consumers and countries. This facilitates an increase in the quality of the brand and the growth of market capitalization of companies. The presented list of directions is not exhaustive, but it reflects the opportunities in the sphere of product quality management in the conditions of the focus on digital technologies.

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Nodira B. Abdusalomova
Tashkent State University of
Economics, Tashkent, Uzbekistan
abdusalomova2016@mail.ru
ORCID 0000-0001-5958-6964

Tatiana N. Litvinova
Volgograd State Agricultural
University, Volgograd, Russia
litvinova1358@yandex.ru
ORCID 0000-0003-3101-2621

Anastasia A. Kurilova
Togliatti State University,
Tolyatti, Russia
aakurilova@yandex.ru
ORCID 0000-0002-1943-5675

Larisa V. Shabaltina
Plekhanov Russian University of
Economics, Moscow, Russia
shabaltina.lv@mail.ru
ORCID 0000-0001-6943-629X
