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DIGITAL TRANSFORMATION MODEL OF QUALITY MANAGEMENT SYSTEMS: CONCEPTUAL FRAMEWORK

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Digital quality management systems (QMS) is an essential component for modern business enterprises, as it guarantees homogeneous and cost-efficient products/services at maximum returns and minimum complaints [1, p. 163; 2, pp. 1034-1059]. Digital transformation (DT) refers to the process of reinventing a business using digital technologies to enhance its responsiveness to market demands. It involves integrating new technologies to redesign activities, products, and services, and requires change management to overcome organizational resistance and adapt to the transition. While the term "Digital Transformation" is often used interchangeably with that of Industry 4.0, it has been argued that technology should not be considered as its most important driver, being only a part of the complex puzzle that must be solved for organizations to remain competitive [3, pp. 118–144]. According to [4, pp. 990–1003; 5, pp. 1502–1515], most organizations face challenges when implementing digital technologies in QMS. At the same time, the digital evolution of quality [6] has already become a catalyst for the transition to the concept of Quality 4.0. However, the lack of a unified vision among scientists of a comprehensive model of the QMS Quality Transformation leads to the ineffective use of modern digital technologies. Therefore, the purpose of the study was to develop a conceptual framework for a comprehensive model of DT QMS. Thus, based on the results of the study on the example of the project industry, the main principles of DT QMS are proposed: a) integration: a combination of traditional methods of activity with modern digital technologies; b) standardization: development of unified protocols for digital models; c) security: ensuring cyber resilience at all stages of the life cycle.

The following are identified as key components of the model: a) Digital Twins: dynamic modeling of physical processes; equipment condition prediction and risk analysis; b) Building Information Modeling (BIM): three-dimensional modeling of objects with integration of geospatial data

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Optimization of infrastructure solutions; c) artificial intelligence (AI) and Big Data: analysis of large data sets for making design decisions; machine learning for optimizing security parameters; d) blockchain: data protection from unauthorized access; tracking of changes in documentation; e) cloud technologies: centralized data storage and processing. remote access for all project participants. The proposed model is based on a systems approach and integrates three key levels of transformation. 1.1. Strategic level. Defining a digital quality strategy; forming a transformation roadmap; setting KPIs. 1.2. Process level. Reengineering quality management processes using: digital twins for simulation; AI analytics for defect prediction; IoT sensors for real-time monitoring. 1.3. Technological level. Solution architecture: dajets – analytics platform – ERP/MES systems, management interfaces. During the study, key components of the DT QMS model were proposed and recommended tools for their implementation are given (Table 1).

Table 1

Key components of the DT QMS model

Component	Contents	Implementation Tools
Strategic Leadership	Digital Quality Policy Development	Balanced Scorecard
Technological Infrastructure	Integration of AI/ML, IoT, Blockchain	Python libraries (TensorFlow, PyTorch)
Quality Management Processes	Automation of FMEA, Control Charts, CAPA	SAP QM, Minitab Connect
Data Management	Creating a Single Source of Truth	Data Lakes, SQL/NoSQL databases
Human Resources Competencies	Digital Quality Training Programs	LMS-platforms (Moodle, Cornerstone)
Cybersecurity	Protecting Quality Data from Cyber Threats	ISO/IEC 27001

At the next stage of the study, a step-by-step algorithm for model implementation was proposed.

Step 1. Diagnosis of the current state. Conducting an audit using an audit methodology based on a weighted expert assessment, for example, according to the methodology [7, pp. 99–102]. The assessment criteria are not specified (for example, which components are assessed: equipment, personnel, software, etc.). This is a simple mathematical approach, easy to implement and allows you to quickly obtain an integral indicator. The disadvantages of this approach include subjectivity - assessments on the scale depend on experts and may be inaccurate. The following can be used to improve: add dynamic weights (for example, based on AHP analysis); include objective metrics (for example, the number of defects, downtime); use a questionnaire together with data analysis to reduce subjectivity.

Step 2. Development of the solution architecture. The choice of technologies is based on the assessment of the following indicators: efficiency – possible improvement in productivity; compatibility – integration with existing IT infrastructure; cost – capital and operating costs. The formula takes into account key factors for decision-making. Provides a quantitative assessment that simplifies technology comparison. The disadvantages of the proposed approach include the following: uncertainty of metrics – how exactly are "efficiency" and "compatibility" measured?; lack of restrictions – some technologies may be prioritized by the formula, but unacceptable due to other factors (e.g., security); linear dependence – it is difficult to take into account nonlinear effects (e.g., critical but expensive solutions). To improve this step, you can: add additional criteria (e.g., scalability, vendor support); use multi-criteria analysis; introduce restrictions (minimum efficiency, maximum budget).

Step 3. Pilot implementation. Selection of critical processes for automation (e.g., input control). Use of Agile methodology (sprints, e.g., two-week sprints). The advantages of this step are: focus on the most important processes with maximum effect; the iterative approach allows for rapid adaptation. The disadvantages of this step include: lack of criteria for process selection – why input control, and not logistics or production; risk of incomplete implementation – Agile can lead to fragmented results without a clear plan; need for high discipline – if the team is not experienced in Agile, delays may occur. Improvements can be implemented if: use Pareto analysis to select processes (80% effect from 20% of effort) or apply the methodology [8, pp. 263–292]; conduct Agile training for the team.

Step 4. Performance assessment. Calculation of ROI. This is a simple and understandable indicator for assessing financial efficiency. However, the disadvantages of such an assessment include the following: does not take into account indirect benefits (quality improvement, customer loyalty). Depends on the accuracy of the savings forecast – if the data is inaccurate, the ROI will be incorrect. Does not include the time factor (as an alternative, it is better to use NPV or IRR). Improvements can be made by: adding qualitative indicators (e.g., staff satisfaction); using dynamic models (DCF, IRR); conducting sensitivity analysis to assess risks. Thus, the proposed model provides a holistic approach to the digital transformation of the QMS and has a clear structure. The proposed model integrates the strategic, process and technological levels. The key factor for success is the synchronization of technological and organizational changes. The greatest effect is achieved with the parallel implementation of AI/IoT technologies, process changes, and personnel training. This model is universal, easily adaptable to ISO 9001:2015 and can be adapted for specific solutions taking into account industry requirements and the level of digital maturity of the organization. However, its implementation requires a high initial cost of IoT solutions; the need for in-depth retraining of personnel; cybersecurity risks for IoT devices. Future refinement is possible in terms of: defining more flexible and objective metrics at the diagnostic stage; simplifying the complicated technology selection model (multi-criteria analysis); providing clearer criteria for selecting processes for automation; expanding the effectiveness assessment (not only ROI).

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