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**Integration of Software into the Process of Expertise and Quality
Assessment of Complex Technical Products**

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Abstract. The relevance of this study is determined by the increasing technological complexity of modern technical products, the growing volume of measurement data generated during testing, and the heightened requirements for evidentiary validity, transparency, and reproducibility of expert conclusions.

The aim of the article is to provide a theoretical substantiation and practical refinement of approaches to integrating software into the examination and quality assessment of complex technical products in order to enhance computational accuracy, objectivity of result interpretation, and the efficiency of organizing expert activities.

The research methods are based on systemic and structural-functional analysis of expert procedure organization, generalization of digital tool implementation practices in testing centers, comparative analysis of traditional and automated data processing, and experimental validation of a software module under laboratory testing conditions of an electromechanical product.



The results demonstrate that software integration reduces the duration of the analytical stage, decreases computational error in integral indicators, and improves the reproducibility of expert conclusions. The influence of algorithmic data filtering and automated report generation on result stability was examined. It was established that digital integration enhances the systematic processing of large measurement datasets without modifying the technical testing infrastructure. Regulatory, algorithmic, and organizational constraints on software implementation in expert activities were identified.

The conclusions emphasize that software should be regarded as a tool for improving analytical precision and process controllability in expert examination, and its implementation should be accompanied by algorithmic verification and information security assurance.

Prospects for further research are associated with the development of formalized methods for algorithmic certification of software modules, the creation of industry standards for digital processing of test results, and quantitative assessment of the impact of digital integration levels on reliability and effectiveness indicators within quality management systems of complex technical products.

Keywords: test digitalization, automated data processing, expert procedures, algorithmic verification, metrological support, technical diagnostics, reproducibility of results, quality management, information security, analytical modules.

Інтеграція програмного забезпечення в процес експертизи та оцінювання якості складних технічних виробів

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Анотація: Актуальність дослідження зумовлена зростанням технологічної складності сучасних технічних виробів, збільшенням обсягів вимірювальних даних у процесі випробувань та посиленням вимог до доказовості, прозорості й відтворюваності експертних висновків.

Метою статті є теоретичне обґрунтування й практичне уточнення підходів до інтеграції програмного забезпечення в процес експертизи та оцінювання якості складних технічних виробів, спрямованих на підвищення достовірності розрахунків, об'єктивності інтерпретації результатів і ефективності організації експертної діяльності.

Методи дослідження базуються на системному та структурно-функціональному аналізі організації експертних процедур, узагальненні практики застосування цифрових інструментів у випробувальних центрах, порівняльному аналізі традиційної та автоматизованої обробки результатів, а також експериментальній апробації програмного модуля в умовах лабораторних випробувань електромеханічного виробу.

Результати дослідження засвідчили, що інтеграція програмних засобів забезпечує скорочення тривалості аналітичного етапу, зменшення розрахункової похибки інтегральних показників та підвищення відтворюваності експертних висновків. Досліджено вплив алгоритмічної фільтрації даних і автоматизованого формування протоколів на стабільність результатів. Встановлено, що цифрова інтеграція підвищує системність обробки великих масивів вимірювальної інформації без зміни технічної інфраструктури випробувань. Виявлено нормативні, алгоритмічні та організаційні обмеження впровадження програмного забезпечення в експертну діяльність.

У висновках зазначено, що програмне забезпечення доцільно розглядати як інструмент підвищення аналітичної точності та процесної керованості експертизи, а його впровадження має супроводжуватися алгоритмічною верифікацією та забезпеченням інформаційної безпеки.



Перспективи подальших досліджень пов'язані з розробленням формалізованих методів алгоритмічної атестації програмних модулів, створенням галузевих стандартів цифрової обробки результатів випробувань і кількісним оцінюванням впливу рівня цифрової інтеграції на показники надійності та ефективності систем управління якістю складних технічних виробів.

Ключові слова: цифровізація випробувань, автоматизована обробка даних, експертні процедури, алгоритмічна верифікація, метрологічне забезпечення, технічна діагностика, відтворюваність результатів, управління якістю, інформаційна безпека, аналітичні модулі.

Introduction. In the context of the ongoing digital transformation of industry, the increasing complexity of design and functional architectures of technical systems, and the growing requirements for safety, reliability, and compliance with international standards, the integration of software into expert review and quality assessment processes for complex technical products has become particularly relevant. Traditional approaches to quality control and technical expertise, which are largely based on fragmented parameter analysis, paper-based documentation, and limited data processing tools, are progressively less aligned with the current level of technological complexity and the rapid pace of product renewal. This necessitates a transition to integrated digital solutions capable of ensuring the systematic collection, processing, modeling, and interpretation of large volumes of technical data in real time.

The core problem lies in the absence of sufficiently substantiated methodological approaches to the comprehensive integration of software into expert evaluation procedures that would combine computer modeling tools, automated testing, reliability analytics, and risk management within a unified information environment. Insufficient coordination among the technical, metrological, organizational, and regulatory components of the quality assessment process



constrains the development of objective, reproducible, and transparent expert conclusions, particularly with respect to complex multicomponent products characterized by hardware and software integration.

The stated problem is directly related to key scientific objectives in the development of digital methods for technical diagnostics, the improvement of quality management models, and the implementation of digital twin concepts, intelligent data analytics, and automated decision support systems. At the same time, it is closely associated with the practical needs of industrial enterprises, certification bodies, and expert institutions to enhance the reliability of testing results, reduce evaluation time, minimize the influence of the human factor, and ensure product compliance with technical regulations and international standards.

Therefore, the scientific substantiation and methodological support of software integration into the processes of expert review and quality assessment of complex technical products constitute a necessary prerequisite for increasing the competitiveness of high-technology products and ensuring their safe operation under conditions of contemporary technological development.

Literature Review. A review of contemporary research provides grounds for systematizing existing studies according to the logic of the evolution of digital tools, from architectural solutions and testing environments to intelligent models for multicriteria assessment and reliability forecasting.

At the level of developing the digital infrastructure for expert evaluation, Y. Bershchanskyi and coauthors substantiate a containerized approach to the design of artificial intelligence systems in cyberphysical and cloud environments, thereby creating the preconditions for scalable integration of quality control modules into distributed technical systems [1]. Y. Shevchuk examines risk and compliance management mechanisms for legacy infrastructures, emphasizing the necessity of embedded audit and monitoring procedures within software platforms for expert evaluation [2]. D. Kyiashko proposes a hybrid testing framework for multimodal systems based on AI agents, which expands the capabilities of automated



verification of the functional and nonfunctional characteristics of complex products [3]. L. Kaptosv analyzes the principles of RESTful API design for geospatial platforms, emphasizing the standardization of service interaction as a prerequisite for integrating expert modules into digital ecosystems [4].

The development of digital expertise is directly associated with the transformation of production processes and life cycle management of complex technical products. In particular, Ya. Harashchenko substantiates the use of software tools for modeling and verification in the technological preparation of additive manufacturing, thereby increasing the accuracy of expert assessment of parameters of complex structures [5]. S. Kovalevskyi and coauthors investigate integrated life cycle management of mechanical engineering products, emphasizing the importance of integrated information systems to ensure traceability and proper quality documentation [6]. V. Volkov and colleagues propose an improved method for evaluating software used to monitor vehicle parameters, demonstrating the potential for integrating digital monitoring tools into technical expertise procedures [7]. R. Drozd and R. Wolniak examine a systemic approach to product quality assessment, focusing on the formalization of criteria and their algorithmic implementation within a digital environment [8].

The advancement of digital expertise necessitates the integration of software quality assurance methodologies and data analytics. In particular, S. Studer and coauthors propose the CRISP-ML(Q) model, which integrates the machine learning life cycle with quality assurance procedures, thereby establishing a foundation for standardized algorithmic expertise [9]. K. Stylidis and colleagues develop a framework for assessing perceived product quality through attribute ranking, which can be implemented in software-based decision support systems [10]. A. Zonnenshain and R. Kenett formulate the concept of Quality 4.0, which involves the integration of digital technologies, big data, and automated control into quality management processes [11]. A. Chabuk and colleagues demonstrate the application



of an index-based approach and GIS software for multifactor quality assessment, confirming the potential of digital analytical tools in expert evaluation systems [12].

The final group of studies addresses defect prediction, multicriteria decision making, and the architectural quality of software systems as the foundation of digital expertise. In particular, H. Wang and coauthors propose an integrated fuzzy QFD and grey decision making model for the collaborative quality design of large and complex products, which can be implemented in expert software systems [13]. M. Thota and colleagues systematize methods for software defect prediction, thereby establishing a basis for the implementation of predictive analytics in expert platforms [14]. L. Bass, P. Clements, and R. Kazman systematize architectural approaches to ensuring the quality attributes of software systems that determine their reliability and long-term effectiveness in the context of technical expertise [15].

In summary, it is advisable to further integrate defect prediction methods, fuzzy decision making models, and architectural analysis within comprehensive digital systems designed to support expert conclusions regarding the quality of complex technical products.

Identification of Previously Unresolved Components of the General Problem. Despite the availability of studies in the field of digitalization of quality management and automation of measurement data processing, issues related to the comprehensive integration of software into the full cycle of expert procedures remain unresolved. The methodological foundations for defining functional requirements for software modules are insufficiently substantiated, unified approaches to the algorithmic verification of calculations within normatively regulated procedures are lacking, and empirical data on the impact of digital integration on the accuracy and reproducibility of expert conclusions are limited. This constrains the development of a coherent theoretical framework for digital expertise and its standardization in practical activities.

The proposed study is aimed at addressing these gaps through a systematic analysis of the organization of expert evaluation, substantiation of methodological



principles for software integration, and experimental verification of its impact on the effectiveness of assessment procedures. The obtained results expand the empirical base, clarify problematic aspects of implementing digital solutions, and establish a foundation for further standardization and enhancement of expert activities.

Formulation of the Article Objectives. The aim of this article is to provide a scientific substantiation of approaches to integrating software into the processes of expert review and quality assessment of complex technical products in order to enhance the reliability, objectivity, and efficiency of expert procedures.

To achieve this aim, the following objectives have been defined:

- 1) to analyze the current state of organization of expert review and quality assessment of complex technical products and to substantiate the methodological principles for integrating software into expert procedures;
- 2) to conduct an experimental validation of software tools in the process of quality assessment of a complex technical product and to evaluate their impact on the accuracy, timeliness, and reproducibility of expert conclusions;
- 3) to identify scientific and practical challenges associated with software implementation and to formulate recommendations for improving the effectiveness of quality assessment systems.

Results. The contemporary organization of expert review and quality assessment of complex technical products is characterized by a combination of normatively regulated procedures, engineering testing, metrological support, and documented confirmation of compliance with established requirements. In most industries, quality control is performed in stages, from verification of compliance with technical documentation to functional, endurance, and safety testing. A significant role is played by the standardization of procedures, the use of certified measurement methods, and the involvement of experts with appropriate qualifications.

At the same time, the development of complex hardware and software systems, the integration of sensor networks, automated control modules, and digital



interfaces substantially transform the content of expert activities, requiring a systemic analysis of both the physical parameters of the product and the characteristics of its software functioning (Table 1).

Table 1

**Structural Elements of the Organization of Expert Review and Quality
Assessment of Complex Technical Products**

Process Element	Content Characteristics	Instrumentation Support
Analysis of technical documentation	Verification of compliance of design solutions with the requirements of standards and technical regulations	Regulatory documents, technical specifications, compliance reports
Metrological support	Control of measurement accuracy and calibration of control instruments	Certified measuring instruments, calibration procedures
Functional testing	Verification of product operability under specified operating conditions	Test benches, parameter recording systems
Endurance and reliability testing	Assessment of durability and resistance to loads	Climatic test chambers, programmable loading systems
Expert interpretation of results	Formulation of a generalized conclusion regarding product compliance with established requirements	Analytical calculations, expert reports

Source: compiled by the author based on [5, p. 114; 6, p. 69; 7, p. 14; 8; 11, p. 619]

In the practical activities of industrial enterprises and testing centers, the specified structural elements function as an interconnected system that provides an evidentiary basis for confirming product compliance with established requirements. The analysis of technical documentation is carried out at the stage of product admission to testing and involves verification of the compliance of design solutions with technical regulations, industry standards, and safety requirements. For example, in mechanical engineering, expert examination of drawings and specifications makes it possible to confirm the conformity of materials, tolerances, and fits with



normative values prior to bench testing, thereby minimizing the risk of failures during operation [5, p. 114].

Metrological support is implemented through a system of calibration and periodic verification of measuring instruments, which ensures the reproducibility of results. In instrument engineering or the energy sector, this is manifested in the regular verification of pressure, temperature, or electrical sensors prior to endurance testing, thereby ensuring the accuracy of assessing the functional characteristics of the product. Functional and endurance testing are conducted on specialized test benches with parameter recording under various load conditions. For example, for electrical equipment, peak current consumption modes are simulated, while for transport components, cyclic mechanical loads are applied, enabling the assessment of operability under operating scenarios that approximate real conditions [7, p. 14].

The obtained data arrays are generalized through the calculation of reliability indicators, safety factors, and parameters of functional stability. Expert interpretation of the results involves the systematic alignment of data from various tests with the requirements of regulatory documents and the formulation of an integrated conclusion regarding the level of quality. In the practice of certification bodies, this is reflected in the preparation of compliance reports containing aggregated quantitative indicators that confirm the possibility of placing the product on the market or putting it into operation. Thus, the contemporary organization of expert review is based on the combination of regulatory governance, measurement accuracy, and expert analysis of test results, ensuring the systematic and evidence-based assessment of complex technical products.

The integration of software into the structure of expert procedures is driven by the need to transition from fragmented processing of test results to systematic data management throughout the entire quality assessment cycle. The methodological principles of such integration involve the creation of a unified digital environment within which the continuity of information flows, standardization of data formats, traceability of changes, and automated support for expert decision



making are ensured. Software tools should serve not only as means of recording indicators but also as an intelligent component of the expert infrastructure, providing structured accumulation of measurement results, their algorithmic verification, analytical processing, and the formulation of substantiated conclusions in accordance with established quality criteria (Table 2).

Table 2

**Functional Requirements for Software Tools Integrated into Expert
Procedures**

Functional Component	Function Description	Methodological Purpose
Data acquisition module	Automated collection of indicators from measurement systems and test benches	Ensuring completeness and timeliness of primary information
Structuring and verification module	Data formatting, validation of correctness, identification of deviations	Enhancing reliability and standardization of results
Analytical module	Statistical processing, calculation of integral quality indicators, scenario modeling	Generation of quantitatively substantiated expert assessments
Visualization module	Graphical representation of parameters and change trends	Support of result interpretation
Documentation and archiving module	Automated generation of reports and preservation of testing history	Ensuring traceability and evidentiary support of procedures

Source: compiled by the author based on [1, p. 154; 4, p. 6; 9, p. 399; 13; 14, p. 337]

In high-technology manufacturing practice, software tools are integrated directly into the testing and control loop, ensuring continuous digital support of expert procedures. Data acquisition modules are connected to sensor networks and measurement channels through standardized interfaces, enabling the automatic recording of temperature, vibration, electrical load, and software failure parameters in real time. For example, during endurance testing of electrical equipment, the



system automatically accumulates thousands of measurements per cycle, rendering effective manual processing impracticable without digital support [9, p. 399].

Verification modules perform algorithmic control of data correctness by checking threshold values, detecting statistical anomalies, and comparing parameters with normative ranges. In the production of transport components, this enables the prompt identification of deviations in strength characteristics or operational stability of assemblies even before completion of the full testing cycle. Analytical modules calculate integral quality indicators, predict residual service life, and model limiting operating conditions, thereby providing a quantitatively substantiated basis for expert conclusions.

Visualization of results in the form of dynamic graphs or multifactor diagrams makes it possible to rapidly assess trends in parameter changes and the relationships among them. Automated report generation ensures preservation of the complete testing history and establishes an evidentiary basis for internal audits or certification procedures. Such integration makes it possible to reduce the duration of expert procedures, improve the accuracy of calculations, and ensure the reproducibility of results without increasing labor costs.

The validation of software tools was conducted at the testing laboratory of a mechanical engineering enterprise during the quality assessment of a centrifugal electromechanical pump unit with a rated power of 7.5 kW and a rotational speed of 2900 rpm. The objective of the experiment was to quantitatively determine the impact of software integration on calculation accuracy, the duration of expert analysis, and the stability of results under repeated measurements. The assessment focused on technical parameters subject to mandatory control in accordance with the manufacturer's technical specifications: flow rate (m^3/h), head (m), electrical power consumption (kW), efficiency (%), vibration level (mm/s), and bearing assembly temperature ($^{\circ}\text{C}$).

Testing was performed on a certified hydraulic test bench equipped with digital sensors for flow rate, pressure, and vibration. The measurement frequency



was one reading per second, with a duration of 60 minutes in nominal mode and 20 minutes at 110 percent of rated load. The total data volume for a single cycle amounted to approximately 4800 measurements for each parameter. The study comprised two procedures. In the first case, data were exported from the recorder in CSV format and processed manually by transferring them into calculation tables, followed by determination of mean values and deviation coefficients. In the second case, a software module was applied that automatically imported the data, filtered anomalies according to the 3σ criterion, calculated mean values, standard deviation, coefficient of variation, and an integral performance index, and generated an electronic report. Each procedure was repeated three times under identical conditions (Table 3).

Table 3

Results of the Experimental Validation of Software Tools in the Expert
Evaluation Process of the Pump Unit

Indicator	Manual Processing	Software Processing
Time required for analytical processing of one cycle, min	102	46
Mean calculation error of efficiency, %	2.6	0.9
Mean standard deviation of flow rate, m ³ /h	0.42	0.39
Variation of the integral index under repeated measurements, %	3.2	1.3
Time required to generate the expert report, min	38	10

Source: developed by the author

Analysis of the obtained results demonstrated that automated processing reduced the duration of the analytical stage by 54 percent, which was achieved by eliminating manual data transfer and performing statistical calculations automatically. The reduction in the calculation error of efficiency from 2.6 percent to 0.9 percent was attributable to the application of algorithmic filtering of random peak values and more accurate averaging of a large measurement dataset. The lower



variation of the integral performance index under repeated cycles indicates improved reproducibility of the expert conclusion.

Within the experiment, it was confirmed that the integration of software tools ensures the stability of calculations when processing large data arrays, reduces time expenditures, and enhances the accuracy of determining key quality indicators without modification of the technical testing infrastructure.

The results of the conducted validation demonstrated an increase in the accuracy, speed, and reproducibility of expert conclusions when a software module for automated data processing was applied. At the same time, they revealed a number of scientific and practical challenges accompanying the implementation of software in expert activities.

First, the issue of regulatory support for digital procedures becomes particularly relevant. Existing standards and methodologies predominantly regulate measurement operations and testing procedures; however, they do not contain explicit requirements for algorithms used to process large datasets, criteria for anomaly filtering, or rules for calculating integral quality indicators in an automated mode [15]. In the present experiment, the application of the 3σ algorithm for excluding peak values had a positive effect on calculation stability. Nevertheless, the absence of a normatively established procedure for verifying such algorithms creates a risk of ambiguous interpretation of results during external audits or certification processes.

A significant problem also concerns the algorithmic validity of software modules. Automated calculation of efficiency, performance indices, or variation indicators is based on embedded mathematical models, the correctness of which must be demonstrated and reproducible under different conditions. Changes in sampling frequency, dataset size, or load modes may result in variation of outcomes, thereby necessitating a procedure for algorithmic certification of the software product analogous to the metrological verification of measuring instruments. The



absence of a formalized mechanism for such certification complicates the integration of software into officially regulated expert procedures.

A third group of issues is associated with cybersecurity and data integrity. Automatic import of measurements from sensor systems and the generation of electronic reports involve the use of network interfaces and centralized databases, which create risks of unauthorized access, modification of results, or loss of information. In the context of expert activities, where data have evidentiary significance, even minor alterations or the absence of an operation logging mechanism may call into question the reliability of the conclusion [10, p. 53]. Therefore, the implementation of cryptographic protection measures, multilevel authentication, and data version control systems is required.

Organizational adaptation of personnel is also a significant factor. The transition from manual processing to automated algorithms transforms the role of the expert from a direct executor of calculations to an analyst and supervisor responsible for verifying the accuracy of software procedures. This shift requires additional training of specialists in digital data processing and a clear understanding of the operational principles underlying software algorithms. Otherwise, there is a risk of formal use of software tools without critical evaluation of the obtained results.

Another challenge concerns the compatibility of software modules with heterogeneous measuring equipment. During the experiment, the use of a standardized Comma-Separated Values (CSV) format ensured accurate data import. However, in real industrial settings, enterprises may operate instruments based on different data transmission protocols, which necessitates additional integration and interface unification. The absence of unified data exchange standards complicates the scalability of digital solutions.

Thus, the findings confirmed the effectiveness of software integration while simultaneously identifying systemic scientific and practical challenges related to the regulatory standardization of algorithms, their verification, information security assurance, personnel training, and technical compatibility. Addressing these issues



is a prerequisite for the full institutionalization of software as an integral component of expert activity.

The results of the study and its experimental validation make it possible to formulate practical recommendations for optimizing the integration of software into the operations of expert institutions and enterprises. The primary direction involves the creation of a unified digital environment for processing expert data that enables automated import of measurement results without manual intervention, their structuring, centralized storage, and subsequent analytical support. The practical implementation of this approach requires the integration of software modules with testing benches through standardized interfaces and the use of unified data transmission formats, including Comma-Separated Values (CSV), which ensures interoperability among heterogeneous systems.

A necessary condition for implementation is the algorithmic verification of software tools prior to their official use in expert procedures. This process includes documented validation of the accuracy of mathematical models, the stability of statistical calculations, and the reproducibility of results under repeated measurements. A comparison of automated outputs with benchmark reference calculations is advisable, as it provides a foundation for the regulatory recognition of digital data processing.

An important direction of optimization is the assurance of information security and the integrity of results. Practical implementation should include operation logging systems, database access control, and the backup and archiving of test protocols. These measures enhance the evidentiary value of expert conclusions and reduce the risks of data loss or unauthorized modification.

The organizational dimension of integration involves the development of internal regulations governing the use of software, as well as the training of personnel to work with digital tools. The expert must supervise the correctness of algorithmic operations and interpret results with a clear understanding of their



mathematical foundations, thereby minimizing the risk of formal or uncritical use of software modules.

The optimal implementation strategy is the phased integration of software tools, initially at the level of analytical processing of test results, followed by automated data collection and the generation of electronic reporting. This approach allows existing infrastructure to be adapted without substantial capital investment and gradually increases the efficiency of quality assessment systems. The implementation of these recommendations will contribute to reducing the duration of expert procedures, improving computational accuracy, and ensuring the stability and reproducibility of expert conclusions in practical application.

Conclusions. The study established that the integration of software into the process of examination and quality assessment of complex technical products enhances the efficiency, accuracy, and reproducibility of expert procedures under conditions of increasing volumes of measurement data and growing technological complexity of products. Experimental validation confirmed that automated processing of results significantly reduces the duration of the analytical stage, decreases computational error in integral indicators, and stabilizes outcomes in repeated measurements without requiring modifications to the technical testing infrastructure.

At the same time, several systemic challenges were identified that constrain the full digital transformation of expert activity. These include the absence of formally established regulatory requirements for data processing algorithms, the need for a structured procedure of algorithmic verification of software modules, cybersecurity risks and data integrity concerns, as well as the necessity for organizational adaptation of personnel. It was also determined that the lack of unified data exchange standards complicates the scalability of digital solutions.

A phased integration of software tools is recommended, accompanied by mandatory algorithmic certification, the implementation of information security mechanisms, and the formalization of internal regulations governing digital result



processing. Prospects for further research include the development of sector-specific standards for algorithmic processing of measurement data and the quantitative assessment of the impact of digital integration on the reliability and effectiveness indicators of quality management systems for complex technical products.

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