Digital Transformation- Integration of Emerging Technologies in ISO/IEC 17025:2017 accredited Testing Laboratories: A Systematic Literature Review

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Abstract. This study provides a systematic review examining the digital transformation of testing laboratories by integrating emerging technologies like Laboratory Information Management System (LIMS), Artificial Intelligence (AI), Digital Twins (DT) and quality management frameworks aligned with IS/ISO/IEC 17025:2017. Despite the growing adoption of digital technologies in the testing laboratories, no consolidated research exists that examines how the emerging technologies align with the ISO/IEC 17025:2017 requirements in the accredited laboratories. This gap turn hinders the systematic implementation and knowledge transfer. This review also identifies a paradigm shift from analog, paper-based operations to intelligent, predictive analytics, automated compliance monitoring and machine-readable metrological traceability, addressing three key questions: (1) What emerging technologies are being integrated into ISO/IEC 17025:2017 accredited laboratories? (2) How do these technologies address specific operational and compliance challenges? (3) What barriers persist in achieving comprehensive digital transformation?" Key findings not only reveal that laboratories leveraging Industry 4.0 technologies report efficiency improvements in routine tasks, though face persistent problems like cybersecurity vulnerabilities, competence gaps, uncertainty and high implementation costs, but also demonstrate that a successful digital transformation requires holistic approach to address technological infrastructure, organizational culture, risk management, harmonization with standards and human-AI collaboration models. The contributions of this study include (1) conceptual frameworks linking LIMS, AI and Digital Twins to ISO/IEC 17025:2017 requirements and (2) identification of critical implementation barriers and future research directions for sustainable digital transformation.

Keywords: IS/ISO/IEC 17025:2017, Laboratory Information Management System (LIMS), Artificial Intelligence (AI), Digital Twins (DT).

1 Introduction

ISO/IEC 17025:2017, as mentioned, is "*the general requirements for the competence, :impartiality and consistent operation of laboratories"* [1]. This standard applies to any type and size of organizations that undertake laboratory activities like testing, calibration or

IICTDS 2025, December 19-20, Chandigarh, India
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DOI 10.4108/eai.19-12-2025.2362723

sampling associated with either testing or calibration. This standard aims to build confidence in laboratory operations by establishing requirements that demonstrate competent and reliable performance, ensuring laboratories produce valid results. Organizations adopting this standard will typically align with ISO 9001 principles. The standard requires laboratories to identify and manage risks and opportunities through planned actions, thereby strengthening their management systems, enhancing operational outcomes, and mitigating potential adverse effects. Laboratories retain the discretion to determine which risks and opportunities are material to their operations and warrant attention. "The use of this standard facilitates cooperation between laboratories and other bodies and assists in the exchange of information and experience, and in the harmonization of standards and procedures. The global acceptance of the test results is facilitated, if laboratories conform to this standard" [1].

1.1 Accreditation and its process

As defined by ISO, accreditation as, "a third-party attestation related to a conformity assessment body, conveying formal demonstration of its competence, impartiality and consistent operation in performing specific conformity assessment activities" [2]. Conformity Assessment is a satisfactory demonstration of specified requirements. "Accreditation body is an authoritative body that performs accreditation" [2] and "laboratory is a body that performs the activities like testing, calibration, sampling associated with subsequent testing or calibration" [1]. Testing laboratories are one of the conformity assessment bodies. A functional approach to conformity assessment as derived from [2] is depicted below at Figure 1 for general understanding of the accreditation.

"Accreditation is a credit given by an accreditation body, attesting its technical competence as per specified scope of accreditation, that is planned, operated, implemented, managed and adhered as per a documented quality system" [3]. There are multiple bodies at national, regional and international levels towards the accreditation of laboratories. In India, there are again multiple bodies, "National Accreditation Board for Testing and Calibration Laboratories (NABL) is the primary accreditation body, whose accreditation system is established in accordance with ISO/IEC 17011" [4], Laboratory accreditation is "a third-party attestation related to a conformity assessment body, conveying formal demonstration of its competence, impartiality and consistent operation in performing specific conformity assessment activities" [2]. An accredited laboratory has numerous advantages from Confidence in Testing/ Calibration, emphasis on accuracy to national and internation recognition and repute.

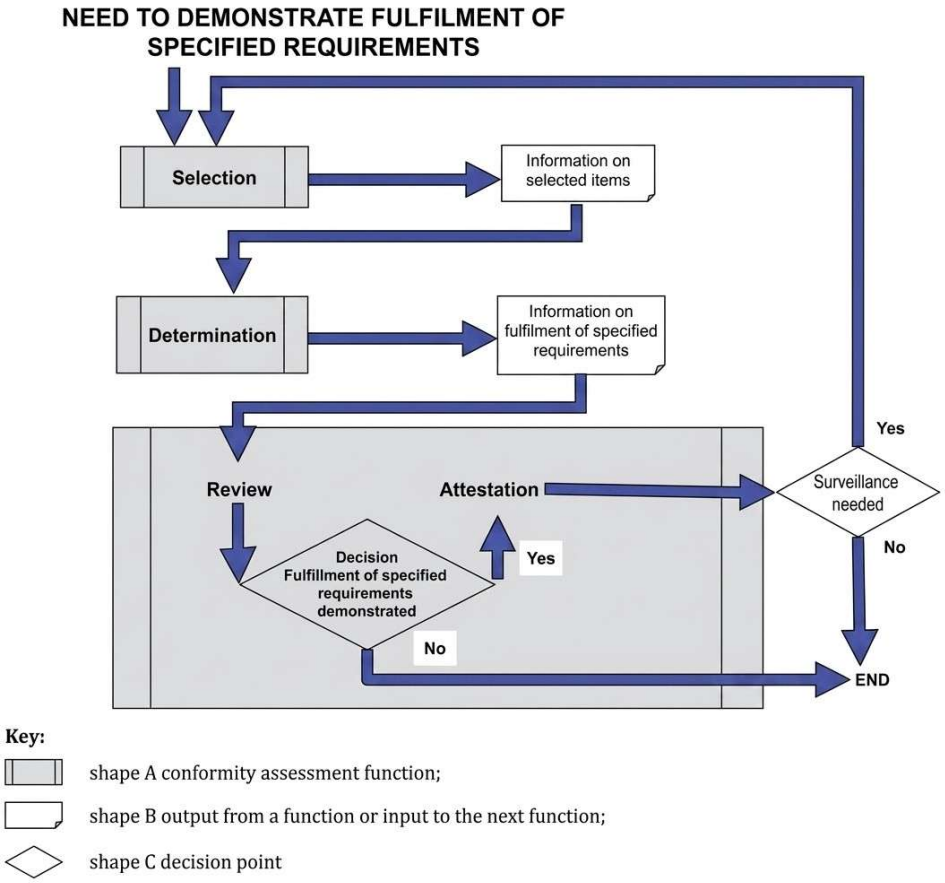


Fig. 1. Functional Approach to Conformity Assessment

NABL provides accreditation to testing laboratories, to Biological, Chemical, Diagnostic Radiology QA Testing, Electrical, Electronics, Fluid flow, Forensic, Mechanical, Non-Destructive and Photometry, Radiological, Software & IT System Testing as per its document, NABL 120- "Guidance for Classification of Product Groups in Testing & Calibration Field" [5]. Furthermore, these fields are divided into groups and sub-groups based on the laboratories scope of test facilities and the product or material types they deal with.

1.2 Understanding the ISO/IEC 17025:2017 standard

The origin of this document traces to a Guide released in the last century named as ISO Guide 25: “Guidelines for assessing the technical competence of testing laboratories”, is considered the first document related to the norm in its current version. ILAC (International Laboratory Accreditation Cooperation) issues this document on October 1st, 1978 [6]. In 1999, this guide is replaced as a standard ISO/IEC 17025: “General requirements for the competence of testing and calibration laboratories” [7]. After its technical revision, the third edition, ISO/IEC 17025:2017 replaces the second edition, ISO/IEC 17025:2005 in 2017.

The structure of the standard is designed in eight clauses, where clauses 1 to 3 are Scope, Normative references, Terms and Definitions respectively and the requirements are set in clauses 4 to 8, named as General, Structural, Resource, Process and Management Requirements respectively. All requirements of this standard are briefly described in the following paragraphs:

1.2.1 General Requirements. This is a clause of general requirements, mentioning about the *impartiality* in undertaking the laboratory activities and *confidentiality* of obtained information about the customer and their requests and reports, and generated information about the laboratory activities and test results etc.

1.2.2 Structural Requirements. This clause discusses about the *organisation structure, management, authority and responsibility etc. including the location and type of facility of the laboratory*. It shall define the authority and responsibility of personnel and their interrelationships, range of laboratory activities that it conforms to and shall be updated and maintained on an ongoing basis.

1.2.3 Resource Requirements. This clause is sub divided and the details are as follows:

General. “A laboratory shall have available the *personnel, facilities, equipment, systems and support services to manage and perform the whole range of laboratory activities”*.

The Resource requirements clause is sub divided into Personnel, *Facilities and Environment Conditions, Equipment, Metrological Traceability and Externally Provided Products and Services.* The requirements and conditions are neatly described and mentioned respectively in their concerned sub clauses.

1.2.4 Process Requirements. The process requirements describe how a laboratory has to manage its testing and calibration activities starting from receiving a test request to issuing the report and handling of complaints/ issues, so that the results are technically valid and reliable. In simple terms, the lab must first review requests, tenders, and contracts to ensure requirements are clear and that it has the competence and resources to undertake the work. It then has to use appropriate, selected, verified/ validated methods, supported by suitable

sampling plans, wherever applicable. Proper handling, identification, and storage of test and calibration items. The lab must keep complete technical records, evaluate measurement uncertainty where relevant, and monitor the validity of results using activities such as quality control, proficiency testing, or repeat measurements. Finally, the laboratory must report results clearly and accurately (including any statements of conformity), manage complaints and nonconforming work through defined procedures and ensure that all data and information are properly controlled in a secure manner, through a validated information management system. A possible representation of the flow of activities or laboratory processes that is adapted from annexure B of ISO/IEC 17025:2017 is shown below in Figure 2.

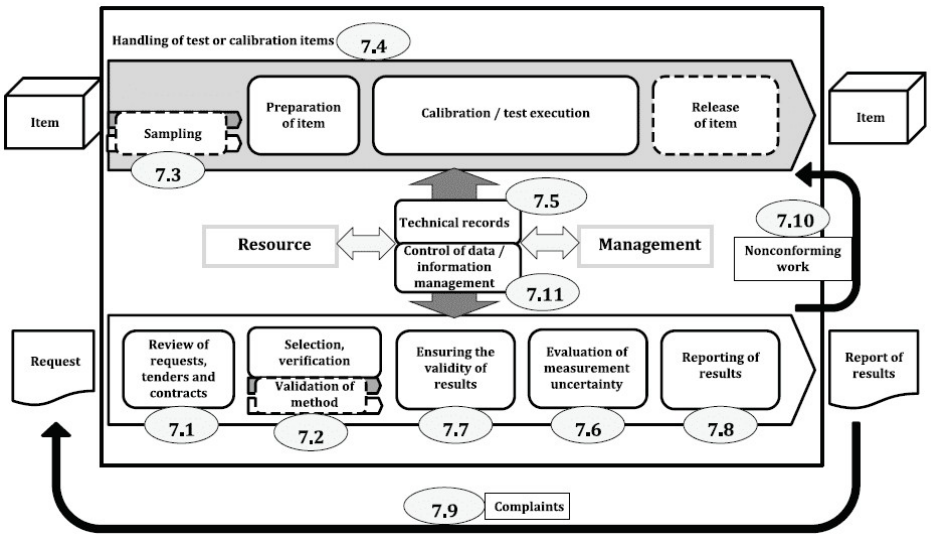


Fig 2. Possible representation of activities under Laboratory Processes

The process requirements clause is the largest section of this standard and the sub clauses mentioned under the process requirements are the core of the standard as it involves all major activities of a laboratory. The requirements, documentation, procedures and records that are to be retained, reviewed and monitored are discussed in the respective subclauses.

1.2.5 Management Requirements.

As per the clause 8, of the standard, Management requirements, there are *Two Options (Option A and Option B)* given for Laboratories that "conform to this document will also operate generally in accordance with the principles of ISO 9001".

Option A: As a minimum, “the management system of a laboratory should have management system documentation, control of the same, control of records, actions to address risk and opportunity, improvement, corrective actions, internal audits and management reviews”.

Option B: Applicable to laboratories, that have a management system in accordance of ISO 9001.

As mentioned above, if the laboratories are maintaining a management system according to ISO 9001, then those laboratories come under option B. Elsewhere, the laboratories have to adopt option A and have to meet the following requirements of option A mentioned in the subclauses of management requirements:

According to these requirements, a laboratory must have a documented management system, that is implemented and being continually improved to support valid results and customer confidence. In simple terms, the lab has to define policies and objectives, control documents and records, identify and address risks and opportunities, handle nonconformities and corrective actions and drive improvement. It must also plan and perform internal audits and regular management reviews to check whether the system is meeting the requirements of ISO/IEC 17025:2017 and whether resources or processes need changes. All of this is meant to ensure that the lab operates consistently, fixes problems effectively, and keeps improving over time.

The existing research is limited to the study of specific tools and technologies and their implementation to an individual or type of laboratories, exhibiting three critical gaps:

First, the existing research remains fragmented across different laboratory domains (pathology, forensics, pharmaceuticals, and metrology) without cross-domain synthesis showing common patterns and transferable practices.

Second, most studies focus on isolated technology adoption rather than holistic digital transformation aligned with comprehensive ISO/IEC 17025:2017 requirements spanning structural, resource, process and management system dimensions.

Third, limited research addresses the integration challenges, ethical implications, and organizational change management needed for successful and sustainable digital transformation in accredited environments.

Considering these gaps, it is proposed to review the existing research works that are focussed towards digital transformation of ISO/IEC 17025:2017 accredited laboratories and found that there is no review available on till date addressing the digital transformation in terms of

laboratories that operate as per ISO/IEC 17025:2017 accreditation. This review is conducted to explore the concepts and implementation cases of various emerging technologies in the context of ISO/IEC 17025:2017 accredited laboratories, how and where they are used, identify implementation barriers and enablers and mapping these technologies with respect to the requirements of the standard and how the accreditation can be maintained or continued after the integration of the new technologies.

2. Methodology

This systematic literature review follows PRISMA guidelines and involves three stages. The details of these stages are explained as follows:

2.1 Search Strategy

Searches were conducted across six databases: IEEE explore, Science Direct, ProQuest, Taylor&Francis, EBSCO and Google Scholar for the period between 01 Jan 2018 and 31 Aug 2025. The search strategy employed is by using Boolean operators combining terms “ISO/IEC 17025:2017” AND “digital transformation”.

2.2 Criterial for Inclusion/Exclusion

Peer reviewed, academic journal articles and papers that are available in English and published between 2018 and 2025 focusing on digital transformation in testing laboratories with an explicit mention of the ISO/IEC 17025:2017 standard accreditation are considered for inclusion.

Duplicate and predated i.e. before 2018 publications and non-peer reviewed sources like blogs, trade magazines, white papers etc., are excluded.

2.3 Screening and Assessment

Included studies are assessed for relevance to ISO/IEC 17025:2017 requirements, generalizability of technology discussed across all types of testing laboratories and for methodological rigor.

A summary of this process is shown in a PRISMA flow diagram shown below in Figure 3.

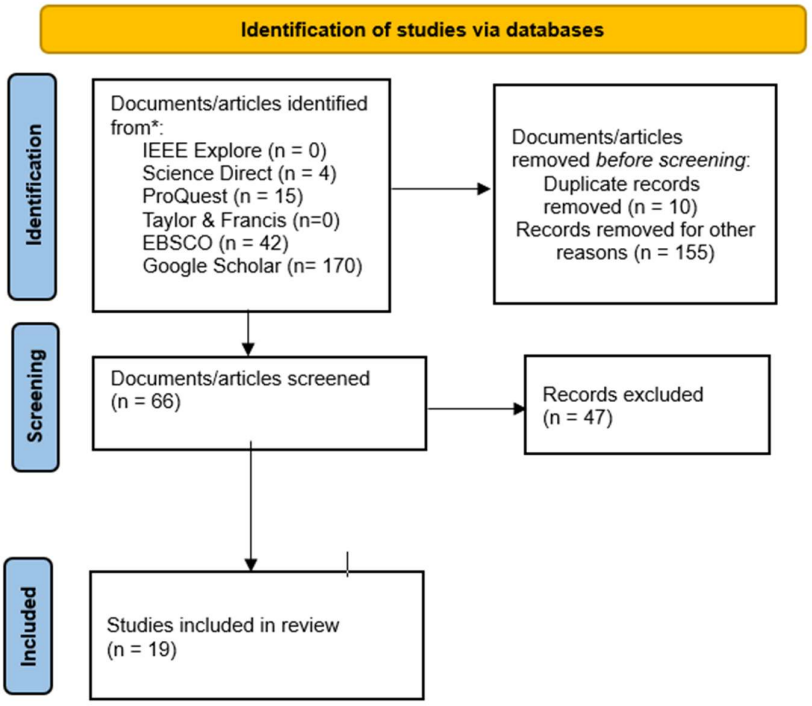


Fig. 3. PRISMA Flow Diagram

3. Literature Review

Emergence of new technologies have been implemented in testing laboratories to make the processes more efficient and less time-consuming.

3.1 Laboratory Information Management System (LIMS)

As mentioned in [1], clause 7.11, the ISO/IEC 17025:2017 standard exemplifies a LIMS, which can be used for collection, processing, recording, reporting, storage or retrieval of data that is generated during the laboratory operations. In simple terms, LIMS primarily manage sample tracking, compliance documentation, and data management. Further, Yuen et al, in [8], conceptualize, create and validate a LIMS 4.0, model, that is developed through gap analysis, through expert interviews and validated via prototype implementation. The LIMS 4.0 model integrates several Industry 4.0 technologies, such as Artificial Intelligence, Digital Twins,

Virtual Reality, Enterprise Resource Planning, Large Language Models each serving a distinct function within the framework of the system. AI is applied within the Certification Knowledge Management (CKM) subsystem, which acts as a dynamic database for test regulations, certification standards, FAQs, and price tables. The continuous integration of artificial intelligence (AI) is reshaping laboratory workflows by automating routine tasks, enhancing data accuracy, and driving innovative breakthroughs in both research and clinical diagnostics [9]. Integrating machine learning (ML) allows laboratory AI to autonomously learn from data and refine processes, which enhances the precision of sample processing and eliminates routine manual mistakes [10], Robotic Process Automation (RPA) and Natural Language Processing (NLP). By using digital twins, that digitally replicate hazardous laboratory processes—such as explosive or high-voltage scenarios, DT enables safe, repeatable training for new engineers. It also enhances testing efficiency by simulating result pathways without needing to occupy physical test stations. Weidlich et al, in their work, demonstrate in their research, that how a process-oriented digital lab twin enhances laboratory management by providing an end-to-end data and process perspective. The digital lab twin facilitates smart decision-making regarding resource allocation and time management, ensuring information transparency and supporting compliance with respect to ISO/IEC 17025 standard [11]. Coupling VR with digital twin, provides immersive interface to trainees through procedural guidance, real-time feedback in simulated environments, and virtual operation of device/equipment or system and facilitating more intuitive and risk-free training outcome. A custom-developed ERP backbone supports the end-to-end operational flow of the laboratory. This encompasses inquiry handling, quotation issuance, client technical communication, project and test scheduling, document control, equipment and calibration management, certification workflow tracking, test plan automation, attendance and HR management, invoicing, dunning, and KPI monitoring. Lab-specific Large Language Model (LLM) to automate customer interaction and internal technical support processes. This LLM-based subsystem provides accurate, context-aware responses to client inquiries regarding international certification requirements, such as required documents, whether local testing is needed, applicable regulations, and certification durations.

3.2 Technologies for Monitoring and Recording

Monitoring and recording of environmental facilities of the laboratory environment is a mandatory requirement as per clause 6.3.3 of ISO/IEC 17025:2017 [1], which is traditionally done by manual checking and recording at regular intervals or at a period that is determined by the quality management system of a laboratory. Whereas, Kelebekler, designes and implementes “an IoT cloud-based monitoring system in order to track temperature and relative humidity values of laboratories of KARTEAM (Kartepe Test ve Arastirma Merkezi-Kartepe Test and Research Center)” [12], a facility in Turkey involved in various testing and research projects located the Uzunçiftlik area of Kocaeli, Turkey. The system consists of three layers namely “sensor nodes, receiver/ transmitter module and IoT-cloud storage”. In normal

conditions, the sensors are in sleep mode and when they are notified, they awake and communicate with transmitter/ receiver module via Bluetooth and transmit the current temperature and humidity data. The master module averages the temperature and humidity values respectively and displays them on an LCD screen with current date/time. The location of the sensors are fixed and is very important, as the values received from the set sensors represent the data of whole room/chamber or area of the laboratory. By unique numbering and designation, the sensors can be identified to which zone they belong to. This system distinguishes itself as it automatically records the environmental data automatically at a preset time, with the existing manual mode of recording and entry of environmental conditions of the laboratory in registers, that requires time and effort of laboratory staff. An additional advantage of this system is that the laboratory staff can monitor these conditions using IoT platform through cloud system from anywhere, whether inside or outside of the laboratory [12].

3.3 Scientific Data Management System (SDMS)

An SDMS, or Scientific Data Management System that is designed to store, manage and manipulate large volumes of scientific data. An SDMS provides robust tools for quality control, data storage, analysis sharing and retrieval. This kind of data management system is essential in research and development laboratories, where complex datasets are handled, including experimental results, simulations, and research data on daily basis [13]. Also, as mentioned in this page, SDMS automatically acquires data from laboratory instruments, electronic files and manual entries and streamlining the collection process and reduces human errors. “It also provides tools for converting, normalizing, and preparing varied datasets to consistent formats suitable for downstream analysis and sharing” [14]. “This system creates a single and secure repository for both structured and unstructured scientific data, supporting version control and efficient organization” [15]. With the advanced security measures such as encryption, user authentication, and access controls, combined with audit trail capabilities, ensure data protection and traceability, this system ideally meets the various requirements of clause 7 and eases the operation of laboratory staff.

3.4 Digital Calibration Certificate (DCC)

The Digital Calibration Certificate (DCC), based on the international standard exchange format XML (Extensible Markup Language) is a unique way of presenting calibration results that replaces the manual certificate and it transfers the calibration data from machine (issuing authority) to machine (calibration customer) in a consistent manner. The XML files can be read by both humans and machines. *The correctness of XML is verifiable by using tools such as well-formedness validation, XML Schema Definition (XSD) or document type definition (DTD), Digital Signature verification and Content Verification*. The integrity and authenticity of the DCCs can be ensured by signing them digitally and encrypting their content. There exists a provision for printing of the document to keep it in black and white from XML using software tools [16]. Production, monitoring and equipment reliability are significantly enhanced when digital measurement systems maintain metrological traceability via DCC

implementation [17]. It is a confirmation through electronic means certifying that "the measuring instrument (MI) has been properly calibrated and the calibration results can be trusted". In contrary with analog calibration certificates, by enabling the seamless transfer of calibration data across diverse facilities and platforms, Digital Calibration Certificates (DCCs) enhance system interoperability while minimizing human-induced errors [18]. DCCs help out in meeting the various equipment (infrastructure) related requirements of clause 6.4 and 6.5 of ISO/IEC 17025:2017 [1].

Djamel Ghernaout et al, in his review, has discussed about overlapping ISO/IEC 17025:2017 into big data [19], that a huge amount of data is present in and around the laboratory generated during the laboratory activities. In addition to the experimental and analytical results, findings can be obtained from its financial management. Big Data through its enormous capabilities of managing details would imbricate ISO/IEC 17025:2017. Though the review has not provided any evidence but has emphasized that, the near future would provide more details of how will be the final figure of this intersection.

3.5 Comparative Analysis of Digital Technologies

Based on the above review of the existing literature, a consolidated comparison of the technologies, laboratory domains, key benefits, ISO/IEC 17025:2017 clauses addressed and their implementation challenges are shown in table 1 below:

Table 1. Comparison of Digital technologies

Sl. No.	Technology	Laboratory Domain	Key Benefits Reported	Implementation Challenges	ISO/IEC 17025:2017 Clauses Addressed
(a)	LIMS	Clinical, Chemical and multiple domains	Reduced errors (30-40%), faster turnaround	High initial cost, staff training	6.4, 6.6, 7.5, 7.11
(b)	AI/ML	Pathology, Analytical	Predictive maintenance, enhanced accuracy	Algorithm bias, validation	6.4, 7.2, 7.7
(c)	Digital Twin	Manufacturing and Testing	Real-time monitoring, process optimization	Data integration complexity	6.3, 6.4, 7.5

3.2 Examples to understand the usefulness of technologies

In this section, the frameworks are mentioned in an example to understand how these technologies benefit in practice.

Example 1. Clinical Testing Laboratory

A mid-sized clinical laboratory (eg. 500 samples/day) implementing comprehensive LIMS, integrated with AI-powered quality control experienced an implementation time of 14 months and staff training of 200 hours covering 15 personnel.

Result: Specific improvements with respect to ISO/IEC 17025:2017 clauses:

(a) Clause 6.4 (Equipment): Automated calibration tracking reduced missed calibrations from 8/year to 0

(b) Clause 7.5 (Technical records): Document retrieval time decreased from 15 minutes to 30 seconds

(c) Clause 7.11 (Control of data): Data integrity audit trails achieved 100% traceability

Example 2. Environmental Testing Laboratory

Upon implementing IoT-based environmental monitoring integrated with Digital Twin modelling, will bring out the following advantages.

Results:

(a) Real-time temperature/humidity compliance monitoring
(b) Predictive alerts reduced out-of-specification events from 12/year to 2/year
(c) Automated reporting to accreditation body during surveillance audits
(d) Clause 6.3 (Facilities): Continuous compliance demonstration vs. manual spot checks"

4. Discussions

From the above review, it is seen how, digitalisation is playing key role in automizing the laboratory process and these emerging digital technologies provide effective, scalable solutions to most process, technical, and documentation challenges recognized in ISO/IEC 17025:2017 implementation literature and real-world case studies. They are most powerful when combined with leadership commitment, a quality-focused culture, and strategy-driven change management. But technology cannot substitute for executive sponsorship and resource allocation.

Below given is a summary of research papers as table 2, that discuss the type of technologies and the clause it addresses in the ISO/IEC 17025:2017:

Table 2. Summary of research papers and technologies discussed

Sl. No.	Technology Discussed	No. of Research Papers	Requirements of ISO/IEC 17025:2017	Process/ Activity addressed by the technology
(a)	LIMS/ LIMS 4.0	4	Clause 7	Laboratory Processes Requirements
(b)	Digital Twin	3	--	Training, Maintenance and Defect identification
(c)	IoT, cloud	1	Clauses 6.3.3	Monitoring and recording of environmental conditions
(d)	SDMS	3	Clauses 7.5, 7.7	Creation and maintaining technical records and ensuring validity of results
(e)	DCC	5	Clauses 6.4, 6.5	Equipment calibration and Metrological traceability

Digitization of laboratory data greatly simplifies workflows and record keeping, improves processes, and makes research and development more efficient [20].

The concept of industry 4.0 is started in 2010s and almost 15 years have passed, due to the fast-advancing technologies, the older systems become outdated day by day and the human race runs towards latest technologies as the generation z occupies the industry and market.

However, the focus now shifts towards industry 5.0, which is starts in 2020s, Industry 5.0 shifts the focus from machines replacing humans to machines and humans collaborating, combining human creativity with machine efficiency for greater flexibility, personalization, and a better overall system [21].

Mustapää et al., quotes that the tangible advantages of digital adoption are frequently minimal for smaller metrology organizations, such as specialized calibration labs [22]. According to the findings [23] of Mian S, the future of the use of AI in test labs is promising, provided responsible and safe use of this technology by ensuring data security, training, provision for technical equipment, ethical considerations and regulatory requirements. In addition, he also emphasized that the survey includes only a limited group of testing laboratories in Slovenia and Croatia, that perform accredited activities according to ISO/IEC 17025:2017 in either full or partial scope and therefore this data could limit in generalising the conclusions at global level.

5. Recommendations

5.1 Roadmap to Harmonization of Standards

(a) Supplementary guidance documents may be developed that specifically address digital technologies within ISO/IEC 17025:2017 framework.

(b) Accreditation bodies may establish assessment criteria for sharing digital transformation.

(c) Harmonize interpretations of Clause 7.11 (Control of data and information management) for AI, ML, IoT and cloud-based systems.

(d) To develop standards for validation of AI in testing laboratories.

(e) To create international consensus on cybersecurity requirements for laboratory information systems.

(f) To revise ISO/IEC 17025 with explicitly incorporating Industry 4.0/5.0 technologies.

(g) To develop machine-readable accreditation certificates and standards for digital traceability.

5.2 Competency Development Framework

Technical Competencies Required:

(a) Literacy about Data science that covers Understanding statistical methods, selection of algorithms and validation approaches.

(b) To impart Cybersecurity awareness skills like Recognizing threats, implementing controls, incident response.

Organizational Development:

(a) To Train the laboratory management and staff for Change management.

(b) To employ Cross-functional teams combining technical expertise and IT/digital skills.

(c) To adopt Continuous learning culture that supports experimentation and innovation.

6. Conclusions and future scope of research

AI in a testing laboratory can be used or applied either individually or through integrating it with other technologies, thereby enhancing the efficiency of that technology. The measurement methods and procedures can be automated and thus the measurement result can be obtained instantly and efficiently. This saves time and effort of laboratory staff, less time means more measurements and more output, relates to timely reporting, customer satisfaction and more revenue, in turn leading to increased efficiency and productivity of laboratory as a whole.

This review reveals a diverse technological landscape addressing critical laboratory management requirements under ISO/IEC 17025:2017. Primarily five technologies are identified as key enablers for laboratory compliance and operational excellence. At first place, LIMS dominates the research focus as it directly supports Clause 7 requirements of laboratory processes. It also reflects the industry's recognition of LIMS as foundational infrastructure for modern laboratory operations. Digital Twin technology addresses essential but often-overlooked domains including training delivery, preventive maintenance, and defect identification—areas not explicitly mapped to specific clauses but critical for sustainable operations, laboratory competency and equipment reliability. DCC systems generate the highest research output, aligning with Clauses 6.4 and 6.5 on equipment calibration and metrological traceability. This underscores the paramount importance of measurement validity and traceability in laboratory activities. SDMS with ensuring proper technical record management and result validity—cornerstones of laboratory documentation and audit compliance. IoT and Cloud technologies represent an emerging area with minimal current research, yet address the critical requirement in Clause 6.3.3 for continuous monitoring and recording of environmental conditions, indicating significant untapped potential for expansion. While research attention varies across technologies, the collective portfolio demonstrates comprehensive coverage of ISO/IEC 17025:2017 compliance domains, with opportunities for deeper investigation into emerging digital technologies, particularly IoT and cloud-based solutions for environmental monitoring and data management integration. Furthermore, to advance this analysis, the discussed technologies have been mapped against the Sustainable Development Goals (SDGs), considering the core objectives and priorities delineated by each goal. Figure 4 below presents a visual representation of this technology-SDG mapping,

illustrating how laboratory technologies contribute to achieving global sustainable development targets.

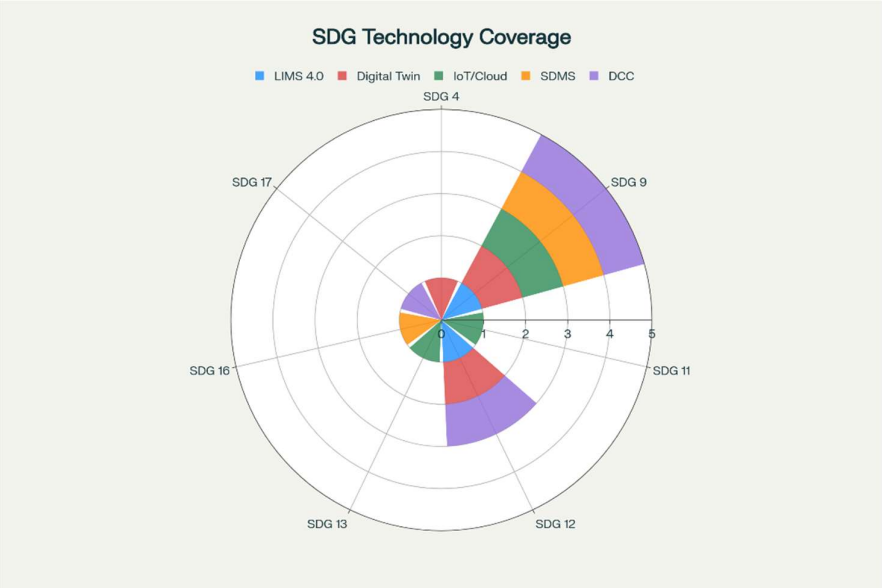


Fig. 4. Alignment of Emerging technologies- SDGs

Industry 5.0 is a model that shifts the focus from technology to human-centric, sustainable, and resilient systems, building on Industry 4.0. It emphasizes the collaboration between humans and advanced technologies like AI and robotics, where machines handle repetitive tasks, and humans focus on creativity, problem-solving and well-being. This approach aims to make production more flexible and to achieve societal goals beyond profit, such as sustainability and worker satisfaction [23].

Further, this review concludes that conduct of impact study in large scale to generalize the advantages and disadvantages of digitalisation or digital transformation or application of emerging technologies in ISO/IEC 17025:2017 accredited laboratories emerge as necessary, which helps the existing and upcoming laboratories in deciding to embrace the digital technologies. In future, this integration of use of AI in ISO/IEC 17025:2017 accredited laboratories demand the revision of the standard to meet the use and management of its use and AI itself. It is also required to analyze the ethical considerations of AI in laboratory processes.

7. Limitations

This study emphasized on descriptive focus of emerging technologies and not delved into the quantitative analysis and financial implications like cost-benefit analysis etc., It also doesn't include the ethical considerations of AI and its governance with respect to quality management of ISO/IEC 17025:2017 accreditation standard.

Acknowledgement

The authors acknowledge that generative artificial intelligence (AI) tools (ChatGPT) were used *solely for grammar correction and language refinement* during the preparation of this manuscript, as the authors are non-native English speakers. No AI tools were used for data analysis, interpretation of findings, generation of ideas, or drafting of the manuscript's content. The authors have thoroughly reviewed and verified all text to ensure accuracy and integrity of the work.

References

[1] International Organization for Standardization: ISO/IEC 17025:2017. General requirements for the competence of testing and calibration laboratories. ISO, Geneva (2017)

[2]International Organization for Standardization: ISO/IEC 17000:2020. Conformity assessment—Vocabulary and general principles. ISO, Geneva (2020)

[3] Patra, N.C., Mukhopadhayay, S.K.: Laboratory accreditation in India including latest ISO/IEC 17025:2017: An overview. Indian J. Pathol. Oncol. 6(1), 1–8 (2019)

[4] National Accreditation Board for Testing and Calibration Laboratories: Introduction. Available at: https://nabl-india.org/introduction/ (accessed: 1 Nov 2025)

[5] National Accreditation Board for Testing and Calibration Laboratories: NABL 120—Guidance for Classification of Product Groups in Testing & Calibration Field. Available at:https://nabl-india.org/nabl/index.php?c=publicaccredationdoc&m=index&docType=both&Itemid=199 (accessed: 1 Nov 2025)

[6] Dos Santos, L.L., Mainier, F.B.: Laboratory quality: Contribution to excellence. In: Anais VI Congresso Nacional de Excelência em Gestão, Niterói, Brazil (2010)

[7] Miguel, A.L.R., Moreira, R.P.L., de Oliveira, A.F.: ISO/IEC 17025: History and introduction of concepts. Quim. Nova 44(6), 792–796 (2021). https://doi.org/10.21577/0100-4042.20170726

[8] Yuen, N.H.-Y., Li, C.-H., Kwok, K.C.-M., Leung, R.: Laboratory Information Management System (LIMS) 4.0: A model to solve the current pain points for commercial electrical and electronic laboratories. Int. J. Eng. Bus. Manag. 17, 1–11 (2025). https://doi.org/10.1177/18479790251385743
[9] Carobene, A., Cabitza, F., Bernardini, S., Gopalan, R., Lennerz, J.K., et al.: Where is laboratory medicine headed in the next decade? Partnership model for efficient integration and adoption of artificial intelligence into medical laboratories. Clin. Chem. Lab. Med. 61, 535–543 (2022)
[10] Agard, M.: Opportunities to transform clinical data intake with artificial intelligence: How these tools can help expand capacity while maintaining compliance. Appl. Clin. Trials 31, 26–28 (2022)
[11] Weidlich, R., Albrecht, T., Derr, P., Röglinger, M.: Designing a process-oriented digital twin for industrial testing laboratories. IEEE Trans. Eng. Manag. 71, 15174–15187 (2024). https://doi.org/10.1109/TEM.2024.3481670
[12] Kelebekler, E.: Monitoring and recording system of laboratory environmental conditions as ISO/IEC 17025 requirement. In: 2021 International Conference on Innovations in Intelligent Systems and Applications (INISTA), 25 Aug 2021. https://doi.org/10.1109/INISTA52262.2021.9548498
[13] LabKey: Scientific data management system definition. Available at: https://www.labkey.com/scientific-data-management-system-definition/ (accessed: 1 Nov 2025)
[14] Agaram Technologies: What is SDMS? Its role in data integrity and compliance. Available at: https://www.agaramtech.com/blog/what-is-sdms-it-is-role-in-data-integrity-and-compliance (accessed: 1 Nov 2025)
[15] Dotmatics: What is a scientific data management system (SDMS)? Available at: https://www.dotmatics.com/faqs/what-is-a-scientific-data-management-system-sdms (accessed: 1 Nov 2025)
[16] Mohammed, S.G., et al.: Towards a new generation of digital calibration certificate: Analysis and survey. Measurement 181, 109611 (2021). https://doi.org/10.1016/j.measurement.2021.109611
[17] Hall, B.D., White, R.M.: Representing metrological traceability in digital systems. In: IMEKO TC6 International Conference on Metrology and Digital Transformation, Berlin, Germany, 19–21 Sept 2022
[18] Korzhak, O., et al.: Digitalization, creation, and implementation of digital calibration certificates. Measurement: Sensors 38(Suppl.), 101467 (2025). https://doi.org/10.1016/j.measen.2024.101467
[19] Ghernaout, D., Aichouni, M., Alghamdi, A.: Overlapping ISO/IEC 17025:2017 into big data: A review and perspectives. Int. J. Sci. Qual. Anal. 4(3), 83–92 (2018)
[20] Comeaga, M.: Digital transformation of the laboratories. IOP Conf. Ser. Mater. Sci. Eng. 1268(1), 012001 (2022)
[21] Rutgers University: Industry 4.0 vs 5.0: What's the difference? Available at: https://engineeringmastersonline.rutgers.edu/articles/industry-4-0-vs-5-0-whats-the-difference/ (accessed: 1 Nov 2025)
[22] Mustapää, T., Nummiluikki, J., Viitala, R.: Digitalization of calibration data management in pharmaceutical industry using a multitenant platform. Appl. Sci. 12(15) (2022). https://doi.org/10.3390/app12157531
[23] Kraaijenbrink, J.: What is Industry 5.0 and how it will radically change your business strategy? Forbes, 24 May 2022. Available at: https://www.forbes.com/sites/jeroenkraaijenbrink/2022/05/24/what-is-industry-50-and-how-it-will-radically-change-your-business-strategy/ (accessed: 1 Nov 2025)