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**QUANTITATIVE ANALYSIS OF MECHANICAL TESTING AND VALVE
PERFORMANCE IN THE OIL AND GAS SECTOR: ENSURING
COMPLIANCE WITH ISO/IEC 17025 IN GLOBAL INDUSTRIAL
INFRASTRUCTURE**

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Abstract

This study addresses the problem that valve qualification decisions weaken when mechanical testing laboratories implement ISO/IEC 17025 unevenly, reducing confidence in test evidence. The purpose was to quantify ISO/IEC 17025 compliance maturity and test which compliance mechanisms predict valve performance assurance (VPA). A quantitative, cross-sectional survey was administered to a purposive sample of 214 professionals in an enterprise oil and gas testing case. The independent construct was ISO/IEC 17025 compliance, measured as D1 competence and authorization, D2 calibration and traceability, D3 method validation and SOP adherence, D4 internal audits and corrective actions, and D5 uncertainty and decision rules; the dependent construct was a composite VPA index. Analysis used descriptive statistics, Cronbach's alpha, Pearson correlations, and multiple regression. Compliance maturity (CI) was moderately high ($M = 3.96/5$) and VPA was moderately high ($M = 3.88/5$), with excellent reliability ($\alpha = 0.92$ and $\alpha = 0.91$). Overall compliance correlated strongly with VPA ($r = 0.71$, $p < .001$), and all dimensions were significant ($r = 0.49$ to 0.66 , $p < .001$). The regression model explained 58% of VPA variance ($R^2 = 0.58$; $F(5, 208) = 57.40$, $p < .001$); D3 was the strongest predictor ($\beta = 0.31$, $p < .001$), followed by D1 ($\beta = 0.24$, $p < .001$) and D2 ($\beta = 0.19$, $p = .001$), while D4 and D5 showed smaller effects ($p \leq .050$). Implications are to prioritize method control and SOP discipline, strengthen competency authorization and traceability, and improve audit closure and uncertainty-based decision rules for integrity decisions.

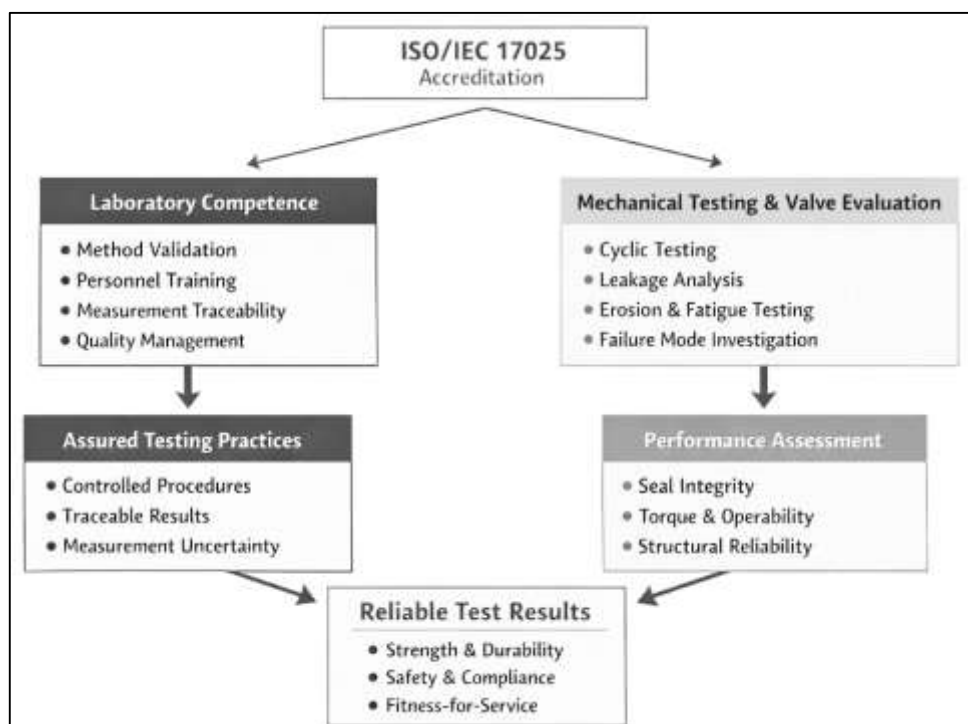
Keywords

ISO/IEC 17025 compliance; Mechanical testing laboratories; Valve performance assurance; Calibration and traceability; Method validation and SOP adherence;

INTRODUCTION

Mechanical testing in industrial engineering refers to standardized experimental procedures used to quantify how materials and components respond to applied loads, including tension, compression, impact, hardness, fracture, and fatigue, so that strength, ductility, toughness, and failure thresholds can be compared against defined acceptance criteria. In oil and gas infrastructure, mechanical testing is routinely coupled with product qualification and in-service integrity assurance because components such as valves, actuators, and pressure-containing parts operate under interacting stressors (pressure cycling, vibration, erosive multiphase flow, corrosion, and temperature gradients) that can shift failure behavior from predictable elastic–plastic response to complex damage modes. Valve performance, in this context, is a measurable ability to achieve intended flow control and isolation with verifiable seat sealing, operability (torque/thrust), structural integrity, and stability across duty cycles; these characteristics are commonly assessed through cyclic testing, leakage characterization, and failure mode investigation under critical operating conditions (Teles et al., 2020).

Figure 1: Mechanical Testing, ISO/IEC 17025 Competence in Oil and Gas Systems



Research on ball-valve degradation shows that leakage signatures can be detected and quantified using pressure/torque or cavity-pressure features, linking operational patterns to measurable deterioration mechanisms and enabling performance evaluation to be expressed quantitatively (Sotoodeh, 2020a). Studies also document how particle-driven erosion at sealing surfaces changes local wear morphology and accelerates leakage probability, which ties mechanical response (surface damage) to functional outcomes (seal failure) in a way that is testable through controlled experiments and computational modeling (Zhang, 2021). In subsea and offshore contexts, reliability demands are elevated by intervention difficulty and cost, so acceptance testing and qualification programs form a central quality gate through which valve and actuator performance evidence is formalized (Sotoodeh, 2022). Across global industrial infrastructure, these definitions become internationally significant because component qualification evidence must remain comparable across laboratories, suppliers, and jurisdictions for procurement, regulatory confidence, and operational safety, and comparability depends on both test method rigor and the competence of the laboratory producing the data (Grochau et al., 2018).

Laboratory competence is formalized through ISO/IEC 17025, which is widely treated in the scholarly literature as a structured set of management and technical requirements intended to ensure that testing

and calibration results are valid, traceable, and produced under controlled conditions. Within this scope, competence is not limited to equipment capability; it includes method validation, personnel competency, impartiality, document control, measurement traceability, and the ability to estimate and manage measurement uncertainty as part of reporting and decision-making. Practitioner and empirical reports describe implementation as a measurable organizational intervention that changes laboratory practices through documented procedures, internal audits, proficiency alignment, and structured corrective actions (Vajda, 2006). Evidence from university and research laboratories indicates that accreditation activities reshape operational routines and governance, with emphasis on systematic documentation and competence demonstration across diverse test types (Arfan et al., 2021; Caten, 2020). Sectoral and geographic analyses further position accreditation as a cross-border mechanism that supports confidence in test data by aligning laboratories to shared competence expectations, allowing results to be interpreted consistently by customers, regulators, and certification bodies (Dora et al., 2017; Jahid, 2021; Akbar & Farzana, 2021). Empirical quality management research also frames ISO/IEC 17025-based systems as instruments that integrate process control, service quality, and operational performance, treating laboratory outputs as service deliverables whose reliability can be assessed quantitatively using survey instruments and performance constructs (Gawor et al., 2021; Reza et al., 2021; Zobayer, 2021a). Case-based studies similarly document how laboratories experience the gains and resource demands of ISO/IEC 17025 adoption, emphasizing how competence demonstration is inseparable from organizational inputs such as management commitment and technical expertise (Abdel-Fatah, 2011; Arman & Kamrul, 2022; Zobayer, 2021b). For oil and gas mechanical testing and valve evaluation, these competence requirements matter because decisions on compliance, acceptance, and fitness-for-service often rely on test results that must withstand external scrutiny; therefore, laboratory governance and metrological discipline become part of the engineering assurance chain rather than a back-office administrative function (Mesbaul & Farabe, 2022; Abdur & Haider, 2022).

A central technical issue within ISO/IEC 17025-aligned testing is measurement uncertainty, which represents the quantified dispersion of values that can reasonably be attributed to a measurand under stated conditions (Mushfequr & Praveen, 2022; Mortuza & Rauf, 2022). In mechanical testing and valve performance trials, uncertainty arises from instrument calibration status, environmental control, operator influences, specimen preparation variability, signal acquisition limits, and model assumptions used to transform raw observations into reported parameters (e.g., leakage rate, torque threshold, erosion depth, or predicted failure probability) (Rakibul & Samia, 2022). The scholarly implementation literature treats uncertainty management as a competence indicator because it determines whether compliance statements are defensible and comparable across laboratories and over time (Abdul, 2023; Abdulla & Zaman, 2023; Lopes, 2014). Conformity decisions also depend on decision rules, which operationalize how measurement uncertainty is accounted for when concluding pass/fail or within/out-of-tolerance outcomes; risk-oriented approaches to ISO/IEC 17025 implementation incorporate these decision rules into management systems so that reporting practices are consistent and auditable (Arfan et al., 2023; Silva et al., 2021; Amin & Mesbaul, 2023). In valve testing, where leakage acceptance thresholds and operability requirements can be narrow relative to operational stresses, the credibility of a conformity statement relies on how uncertainty and risk are embedded into the test design, data processing, and report interpretation (Foyisal & Aditya, 2023; Hamidur, 2023). Recent reliability-focused laboratory literature treats risk management as a structured method for aligning technical uncertainties and operational consequences within day-to-day laboratory control, presenting practical approaches for integrating risk thinking into ISO/IEC 17025 routines (Rashid et al., 2023; Musfiqur & Kamrul, 2023; Santana & Loureiro, 2022). These principles align with engineering reliability work in offshore valve systems where qualification and acceptance tests are used to reduce uncertainty about performance in harsh environments, linking laboratory evidence to system-level reliability arguments (Muzahidul & Mohaiminul, 2023; Amin & Praveen, 2023; Sotoodeh, 2019). In cross-national supply chains, uncertainty-aware reporting supports comparability when multiple laboratories contribute data to vendor qualification or lifecycle integrity decisions, which strengthens traceability of engineering judgments to measurable evidence rather than informal confidence (Hasan & Ashraf, 2023; Ibne & Kamrul, 2023).

Valve performance in oil and gas systems is frequently evaluated through a combination of mechanical integrity evidence and diagnostic signals that reflect degradation. Research on leakage identification has shown that coupling pressure and torque signatures during cyclical testing can distinguish leakage evolution under critical operating conditions, presenting a quantifiable path from raw sensor streams to actionable performance indicators (Mushfequr & Ashraful, 2023; Roy & Kamrul, 2023; Sotoodeh, 2020b). Related studies propose detection devices and analytical methods using valve cavity pressure signals to estimate leakage rates and classify failure modes, allowing internal leakage behavior to be expressed as a predictive modeling target rather than a purely qualitative observation (Shaikh & Farabe, 2023; Shi, 2022; Haider & Hozyfa, 2023). These approaches align with the broader trend in industrial diagnostics that treats valve faults as data patterns within multivariate time series, including stiction behaviors that degrade control loop performance and can be detected using machine learning classifiers with engineered statistical features (Yazdi et al., 2021; Zobayer, 2023). Under oil and gas operating conditions, mechanical wear and erosive damage at sealing interfaces are also documented as primary contributors to leakage and failure, with experimental and computational studies analyzing how particle velocity, impact angle, and material choice influence erosion morphology and rate (Abdul & Shoeb, 2024; Hozyfa & Shahrin, 2024; Zhang, 2023). In subsea systems, valve and actuator reliability is tied to acceptance testing rigor and the realism of qualification programs, with review research emphasizing how test programs are structured to substantiate reliability claims in deep-water contexts (Hasan & Shah, 2024; Hasan & Zayadul, 2024; Shi, 2023). These technical bodies of work collectively define valve performance as a measurable, multi-construct concept that includes sealing behavior, operability, degradation detectability, and reliability under representative loading and environment conditions, all of which can be operationalized into survey constructs and quantitative performance metrics for cross-sectional case-study analysis .

The ISO/IEC 17025 dimension becomes analytically important when mechanical testing outputs and valve performance evidence are treated as compliance-critical data products in global industrial infrastructure. Accreditation studies in higher education and research environments frame ISO/IEC 17025 as an institutional mechanism that increases the formal comparability of results and helps laboratories demonstrate competence to external stakeholders through recognized governance structures (Muzahidul & Aditya, 2024; Hasan & Rakibul, 2024; Shi, 2021). Practitioner reports from specialized laboratories describe accreditation as an operational transformation in which test scopes, traceability chains, and quality controls are made explicit so that external assessments can evaluate competence consistently (Iacob, 2016; Mominul, 2024; Mominul & Zaki, 2024). Quality management research also connects ISO/IEC 17025-aligned practices to measurable operational performance constructs, supporting the idea that competence requirements can be translated into survey indicators and analyzed statistically (Dora et al., 2017; Roy & Praveen, 2024; Rahman et al., 2024). Case evidence from applied laboratory settings emphasizes that implementation is experienced through tangible resource commitments (training, documentation, audits, and method discipline) and that the credibility of test results is grounded in sustained practice rather than one-time certification events (Neves, 2017; Saba & Hasan, 2024; Shaikat & Zaman, 2024). Risk management-focused research extends this by presenting structured models for embedding risk-oriented controls into ISO/IEC 17025 systems, which matters when conformity decisions have safety and financial consequences in industrial applications (Okezue et al., 2020; Sudipto & Hasan, 2024; Haider & Praveen, 2024). When mechanical testing laboratories support oil and gas valve qualification, the “quality system” and the “technical output” become inseparable: a torque threshold, leakage rate, or regression estimate is interpreted through the lens of competence, traceability, and uncertainty controls that define whether the result is fit for compliance decisions in cross-border procurement and regulatory contexts (Zobayer & Kumar, 2024; Zulqarnain & Zayadul, 2024).

This study is designed to quantitatively examine how mechanical testing practices and ISO/IEC 17025 compliance shape valve performance assurance within the oil and gas sector through a cross-sectional, case-study-based approach. The first objective is to measure the current level of ISO/IEC 17025 compliance across the selected case-study context by operationalizing compliance into measurable dimensions such as personnel competence, calibration and traceability discipline, method validation

and procedural adherence, environmental and equipment control, uncertainty handling, documentation rigor, internal auditing, and corrective action effectiveness. The second objective is to quantify valve performance outcomes as a structured set of measurable constructs that reflect functional integrity and operational reliability, including sealing and leakage control, pressure containment confidence, durability under cycling and load variation, stability of operability, and perceived reduction of failure-related rework or nonconformance events. The third objective is to determine the statistical strength and direction of relationships between ISO/IEC 17025 compliance dimensions and valve performance outcomes using descriptive statistics and correlation analysis, allowing compliance maturity and performance assurance patterns to be expressed in interpretable numerical form. The fourth objective is to identify which compliance dimensions act as significant predictors of valve performance through regression modeling while accounting for relevant contextual controls such as respondent role, laboratory function, valve type, pressure class, service severity, and operating environment characteristics. The fifth objective is to develop an empirical compliance-performance model that clarifies how specific laboratory competence elements translate into stronger performance assurance signals, enabling the study to separate high-impact quality practices from lower-impact administrative routines within the same accredited testing environment. The sixth objective is to generate a structured evidence base that supports consistency in mechanical testing governance and performance verification practices across internal teams involved in testing, inspection, quality control, and reliability management within the case-study setting. Collectively, these objectives ensure the study remains tightly aligned with measurable variables, hypothesis testing logic, and statistical validation requirements, while maintaining a clear focus on the practical measurement of compliance maturity and valve performance assurance as quantifiable constructs within an internationally relevant industrial context.

LITERATURE REVIEW

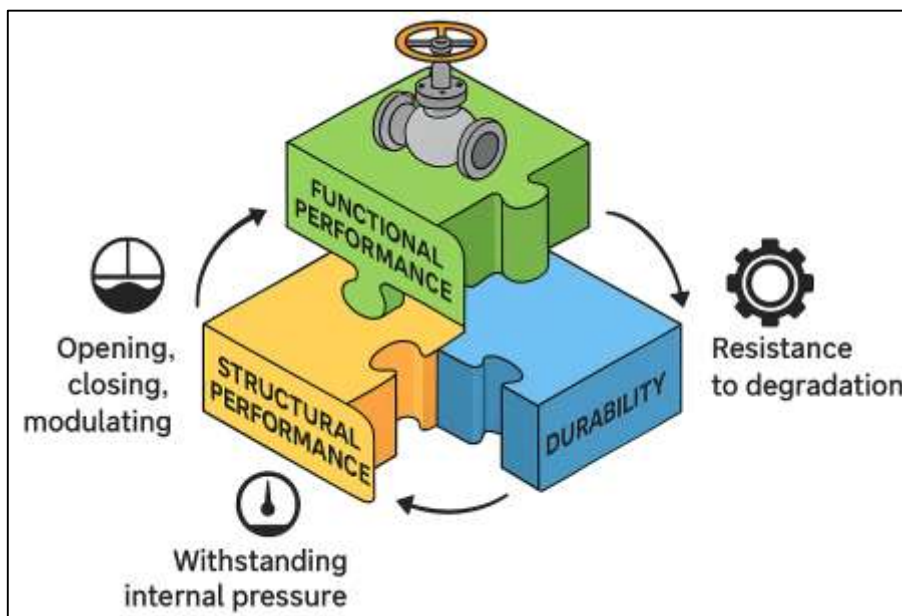
The literature on mechanical testing and valve performance in the oil and gas sector is anchored in the need to generate defensible evidence about component integrity, functional reliability, and operational safety within high-pressure, high-consequence industrial infrastructure. Valves operate as critical control and isolation elements across upstream, midstream, and downstream systems, and their performance is commonly defined through measurable outcomes such as sealing tightness, leakage behavior, pressure containment, operability stability, and endurance under cycling loads. Mechanical testing provides the structured basis for verifying these outcomes by translating material and component behavior into standardized measurements, including tensile and hardness properties, impact resistance, fatigue endurance, pressure boundary integrity, and surface condition effects that influence sealing and wear. In parallel, the credibility of such evidence depends not only on the test methods themselves but also on the competence of the laboratories that design, execute, and report these tests, especially in global supply chains where results must be accepted across organizational and national boundaries. ISO/IEC 17025 serves as the dominant competence framework for testing and calibration laboratories, and its requirements shape how laboratories manage personnel competency, equipment calibration and traceability, method validation, environmental control, measurement uncertainty, reporting integrity, internal auditing, and corrective actions. Literature across quality management, metrology, and industrial engineering conceptualizes ISO/IEC 17025 compliance as an operational capability that influences the reliability and comparability of test outcomes, thereby affecting decision quality in procurement, certification, and asset integrity management. Within this research space, empirical studies increasingly treat compliance maturity and performance assurance as measurable constructs that can be captured through structured survey instruments and linked through statistical techniques such as correlation and regression. Such approaches enable researchers to examine how specific compliance dimensions relate to performance outcomes and to identify which laboratory competence factors act as the strongest predictors of reliable valve performance evidence. Consequently, the literature review for this study synthesizes prior work on valve performance requirements and failure behaviors, mechanical testing methods and uncertainty sources, ISO/IEC 17025 compliance dimensions and implementation realities, and the quality-performance linkage that connects laboratory governance to industrial reliability assurance. This synthesis provides the foundation for selecting a theoretical lens, constructing a conceptual framework, operationalizing

variables into measurable constructs, and justifying the analytical approach used to test the study’s hypotheses within a cross-sectional case-study context.

Valve Performance Requirements in the Oil and Gas Sector

Valve performance requirements in the oil and gas sector are defined as verifiable capabilities that sustain safe containment and controllable flow across high-pressure, high-temperature, and chemically aggressive services. In engineering terms, performance combines functional behavior (opening, closing, and modulating as intended), boundary integrity (withstanding internal pressure without loss of containment), and operability (delivering predictable stem or shaft movement with achievable actuator sizing). These requirements are expressed through measurable acceptance criteria used in qualification, procurement, and maintenance programs: external and internal tightness, allowable leakage limits, pressure-temperature ratings, proof and seat test thresholds, and endurance under specified numbers of cycles (Majumder, 2025; Ara, 2025). For isolation valves, tight shutoff is the dominant functional requirement, so seat design, contact pressure, surface finish, and deformation under load are treated as performance drivers. For control valves, the requirement expands to include stable positioning, repeatable response, and low hysteresis so that process loops can maintain setpoints without oscillation (Habibullah, 2025; Hozyfa & Ashraful, 2025). Operability requirements also include limits on operating torque or thrust, because excessive packing friction or stem drag can create sluggish response, actuator overload, and increased likelihood of leakage at dynamic seals. Accordingly, valve performance is commonly operationalized as a multi-attribute construct that includes sealing capability, mechanical robustness, and functional responsiveness rather than a single metric. Research focused on stem sealing emphasizes that fugitive leakage control is inseparable from operability, because packing configuration, gland stress, temperature cycling, and material choice influence both leakage rates and the torque required to stroke the valve (Jahid, 2025; Asfaquar, 2025; Sotoodeh, 2023). Sealing requirements are often expressed in contact-mechanics terms, where preload and geometric conformity must create a continuous band of contact stress that exceeds fluid pressure at the interface. Work on connector seals shows how preload, contact width, and stress distribution govern sealing reliability under pressure, offering principles for offshore valve service (Foysal, 2025; Islam & Abdur, 2025; Yun et al., 2017).

Figure 2: Core performance dimensions of oil and gas valves



A second layer of valve performance requirements concerns structural behavior and sealing robustness under realistic boundary conditions, because oil and gas valves operate as part of an integrated piping system rather than as isolated components. Pipeline and terminal valves can experience combined loading from internal pressure, thermal expansion, installation misalignment, vibration, and piping

reactions, and these loads can distort the body, shift seats, and change stem alignment in ways that influence sealing contact and operability (Mohaiminul, 2025; Mominul, 2025). Consequently, performance specifications commonly require that valves maintain integrity not only at nameplate pressure but also under representative assembly and support conditions, including end loads, bending moments, and actuation loads (Muzahidul, 2025; Hossain, 2025; Zaman, 2025). Structural requirements are often evaluated through stress and deformation analyses that connect allowable stresses to design codes while also assessing local deformation that may compromise seat contact or sealing interfaces. A case study on a large pipeline ball valve illustrates how stress analysis of the valve body and pup pieces can be used to evaluate stress hot spots, deformation patterns, and load transfer paths for emergency shut-down duty (Akbar & Sharmin, 2025; Hasan, 2025; Sotoodeh, 2021). From a performance perspective, these structural considerations translate into requirements for stable shutoff after thermal or mechanical transients, consistent torque margins for opening after pressure equalization, and predictable behavior during proof testing and partial-stroke checks (Ibne, 2025; Milon, 2025). Control performance adds another structural-operational requirement: the valve must move smoothly and repeatably in small increments so that the controller output maps to a stable process response. When friction, backlash, or deadband dominates valve motion, loop oscillations and poor setpoint tracking can result, so many operators treat stiction as a performance defect with direct production and quality impacts (Farabe, 2025; Kamrul, 2025). Data-driven work on automatic detection and quantification of stiction provides a basis for defining performance limits in terms of measurable nonlinear motion signatures rather than subjective operator judgement (Choudhury et al., 2006; Mushfequr, 2025; Shahrin, 2025).

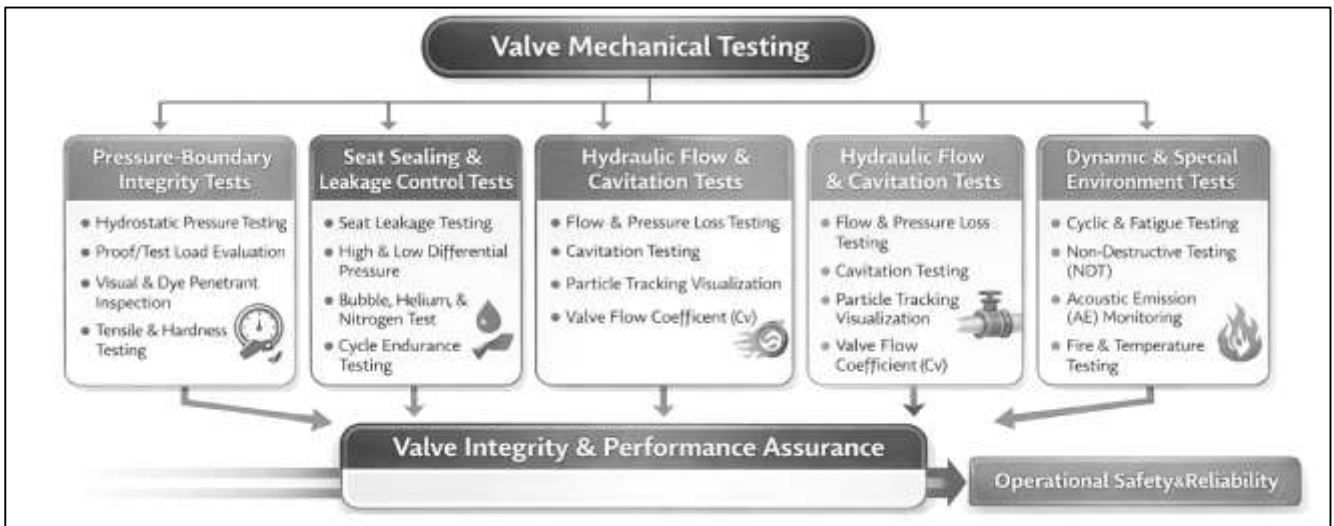
A third set of valve performance requirements arises from degradation mechanisms that progressively reduce tightness and operability, making durability an essential dimension of performance in oil and gas service. Isolation and control valves may be exposed to erosive particles, flashing, cavitation, and multiphase turbulence that remove material from trims and seats, and they may also face corrosion, deposits, and thermal cycling that change friction and seating behavior (Rakibul, 2025; Saba, 2025). Durability requirements therefore extend beyond initial acceptance testing to include resistance to wear, preservation of sealing surfaces, and maintenance of operating margins over long intervals with limited opportunities for intervention (Sai Praveen, 2025; Saikat, 2025). In field terms, the requirement is often framed as sustained ability to meet leakage class and stroke-demand expectations after exposure to representative process conditions, including upset scenarios that accelerate erosion or induce abnormal vibrations (Shaikat, 2025; Shaikh, 2025). Because erosion is strongly dependent on flow regime, geometry, and local turbulence intensity, performance requirements frequently incorporate design controls and inspection expectations aimed at limiting erosive velocity, avoiding sharp turns that concentrate particle impacts, and selecting materials and coatings that tolerate particle-laden flow (Waladur & Hasan, 2025; Haider, 2025). Practical engineering analyses of erosion in offshore piping and valve systems emphasize that erosion damage can present as gradual wall loss as well as rapid local attack at restrictions, downstream of throttling elements, and at regions where flow separation drives repeated particle impingement. Such observations support durability criteria that require both adequate initial thickness and a defensible inspection plan tied to expected erosion rates. Guidance drawn from oil and gas projects also treats erosion prevention as a performance requirement for the testing program itself, because realistic test media selection, cycling, and post-test examination determine whether laboratory evidence reflects the dominant in-service damage modes (Sotoodeh, 2018). When these requirements are specified clearly, operators can compare valve designs and test reports using consistent, quantitative durability indicators across assets.

Mechanical Testing Methods Used for Valves and Related Materials

Mechanical testing for industrial valves in oil and gas is usually organized around three evidence needs: pressure-boundary integrity, seat sealing and leakage control, and flow/operability behavior under representative hydraulic conditions. Pressure-boundary integrity is established through proof-type loading that stresses the valve body, bonnet, end connections, and pressure-retaining joints so that leakage, excessive deformation, or crack initiation can be detected before commissioning. Complementary seat tests evaluate the ability of the closure element and seat geometry to maintain tight shutoff under specified differential pressures, which is fundamental for isolation duty and for

preventing loss of containment across process barriers. A third testing family targets performance as a fluid-control component: how the valve shapes flow, what pressure losses it introduces, and how internal flow features such as separation and recirculation influence stability, noise, and the onset of cavitation. Experimental flow-visualization work on ball valves demonstrates this logic by pairing pressure/flow measurements with particle-tracking methods to map internal flow patterns at different openings and inlet velocities, then linking those patterns to performance coefficients and observable cavitation phenomena (Chern et al., 2007). In practice, these mechanical test families must be coordinated because boundary integrity, sealing tightness, and hydraulic behavior are not independent: small elastic distortions under load can alter seat contact, and internal turbulence or cavitation can accelerate wear that later appears as leakage. For this reason, laboratory programs in the sector often treat “valve performance” as a bundle of measurable outcomes generated by multiple tests rather than a single pass/fail event, and they document test conditions, instrumentation, and measurement uncertainty so results remain comparable across batches and suppliers. Material and weld qualification tests (tensile, hardness, impact, and microstructural checks) also supply baseline property evidence that underpins pressure ratings and fatigue margins, particularly for corrosion-resistant alloys, overlays, and dissimilar-metal joints used in sour or erosive service.

Figure 3: Mechanical Testing Methods Used for Valves and Related Materials in Oil and Gas Applications



Beyond baseline proof and seat tests, oil-and-gas valves are often evaluated with dynamic or service-simulating mechanical tests because many failures are driven by unsteady flow phenomena and cycling rather than static overload. For throttling and partially open conditions, cavitation is a central concern: vapor bubbles form and collapse near surfaces, producing high local pressures that promote pitting, erosion, and rapid degradation of trims and seats. Laboratory strategies therefore combine controlled hydraulic loops, pressure-tap instrumentation, and high-speed or optical diagnostics with numerical models so that cavitation inception and intensity can be related to operating pressures, valve opening, and flow velocity. A representative approach is a combined CFD-and-experiment study of ball valves that validated simulated vapor-volume-fraction trends against experimental observations while varying inlet pressure and assessing flow characteristics inside the valve (Yousaf et al., 2022). Such work clarifies what must be measured in a competent test program: not only differential pressure and flow rate, but also the local conditions that drive bubble formation, the repeatability of opening positions, and the thermal/pressure stability of the test medium. Another dynamic testing priority involves safety and relief valves, where the mechanical question extends to transient forces acting on the disc and spring system during opening, closing, and discharge. In these devices, hydrodynamic forces influence set pressure accuracy, blowdown behavior, chatter risk, and ultimately the reliability of overpressure protection. Experimental studies that directly measure incompressible forces on safety-

valve components provide benchmarks for validating design calculations and for selecting instrumentation ranges and sampling rates in laboratory setups (Chabane et al., 2012). For oil and gas operators, the practical implication is that performance assurance must include time-dependent measurements (force, displacement, vibration, and flow) alongside traditional static readings, because many “passing” valves under static tests can still exhibit unstable dynamics or accelerated damage when exposed to realistic transients and cyclic duty.

Mechanical testing programs also extend into non-destructive testing (NDT) and abnormal-environment tests to capture failure modes that are difficult to reveal with conventional bench procedures. For in-service condition assessment, acoustic emission (AE) has been investigated as a high-sensitivity method for detecting valve degradation and internal leakage by capturing transient stress waves generated by flow through small leak paths, cavitation events, or frictional damage processes. A synthesis of AE-based valve detection research describes how AE systems can be configured for condition monitoring, cavitation detection, and portable field measurements, highlighting the need for signal processing capable of separating leakage signatures from background plant noise (Yan et al., 2015). In an ISO/IEC 17025 context, AE illustrates why method validation and measurement uncertainty matter: the measurand is indirect (signal features rather than leakage volume), so laboratories must demonstrate detection limits, repeatability, and decision thresholds that translate signals into defensible accept/reject outcomes. Abnormal-environment testing is equally important for valves installed in hydrocarbon facilities where external fire exposure can occur. Fire type-testing does not only test survivability of materials; it challenges bolted joints, flange interfaces, and assembly tolerances as thermal expansion and gasket relaxation evolve rapidly. A comparative leak-tightness study of wafer and lug-wafer valve configurations during a fire examined how differential thermal expansion in bolting and body components can cause joint looseness and leakage escalation, thereby motivating test scenarios that include thermal gradients and restraint effects rather than uniform heating assumptions (Cheta & Jung, 2012). When combined, NDT-oriented methods like AE and extreme-condition tests like fire exposure broaden the evidence base beyond routine pressure and seat checks, enabling laboratories to link mechanical-test observations to credible statements about valve integrity under the operational disturbances that dominate major-accident risk in oil and gas facilities. These additional methods also support maintenance prioritization and root-cause investigations.

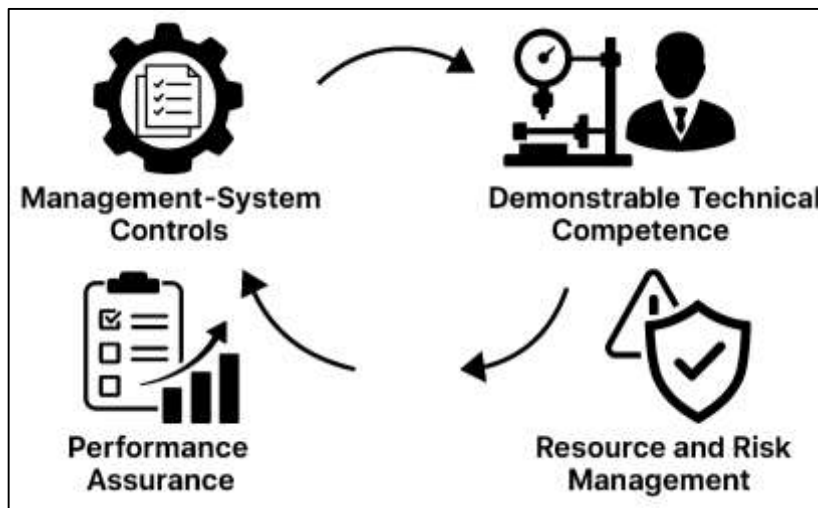
ISO/IEC 17025 Compliance Mechanisms in Testing Laboratories

ISO/IEC 17025 compliance is operationalized through a connected set of management-system controls and technical-competence practices that allow a laboratory to demonstrate that results are valid, traceable, and consistently produced under controlled conditions. In practice, the standard is not “implemented” as a single document-set; it is enacted as an end-to-end workflow that starts with how work is planned, authorized, performed, verified, and reported. University-laboratory experiences remain useful in clarifying these mechanisms because they highlight the practical translation of clauses into daily routines and records. For example, early implementation accounts emphasize that competence is proven through disciplined control of procedures, calibration status, environmental conditions, staff authorization, and reporting rules, with special attention to the instability of staffing and schedules that can undermine routine quality controls if governance is weak (Zapata-García et al., 2007). Similarly, studies describing implementation in complex institutional environments show that “system fit” matters: compliance improves when QMS elements are mapped to real processes, indicators are defined for monitoring, and responsibilities are anchored in workflows rather than being treated as extra paperwork (Grochau et al., 2010). These perspectives matter for industrial mechanical testing because such laboratories often operate under high throughput, strict turnaround expectations, and safety-critical performance requirements, making process clarity and evidence-based control central to both compliance and operational credibility. In effect, ISO/IEC 17025 becomes a compliance architecture: it structures how inputs (people, instruments, methods, samples) are stabilized so that outputs (test results and conformity statements) remain technically defensible across time, personnel changes, and audit scrutiny.

A second compliance mechanism is performance assurance through external comparison and structured internal verification, which operationally connects technical competence to measurable

outcomes. Interlaboratory comparison and proficiency testing are not merely audit “checkboxes”; they provide quantitative signals of method performance and analyst consistency and can reveal systematic biases that routine internal checks fail to detect. Evidence from proficiency-testing contexts indicates that laboratories operating under an ISO/IEC 17025-aligned quality system can show measurably stronger performance patterns – such as better distributions of z-scores and higher rates of satisfactory outcomes – than laboratories without a comparable system structure, supporting the logic that compliance mechanisms improve result validity at scale (Albano & Faustini, 2016).

Figure 4: Integrated management and technical competence mechanisms



For mechanical testing and valve-performance evaluation, this principle aligns directly with compliance assurance: if a laboratory claims competence for tensile, hardness, impact, or pressure-cycle testing, then sustained comparability – across operators, instruments, and batches – must be evidenced through repeatable measurement performance and documented validity checks. The practical implication at the compliance-mechanism level is that laboratories must design an evidence loop: define acceptance criteria, implement monitoring (control charts, replicate tests, reference materials where feasible), participate in appropriate comparisons, and translate deviations into corrective actions with traceable closure. A standards-based system becomes persuasive only when data trails demonstrate that variation is detected, interpreted, and reduced in a disciplined manner rather than explained away informally.

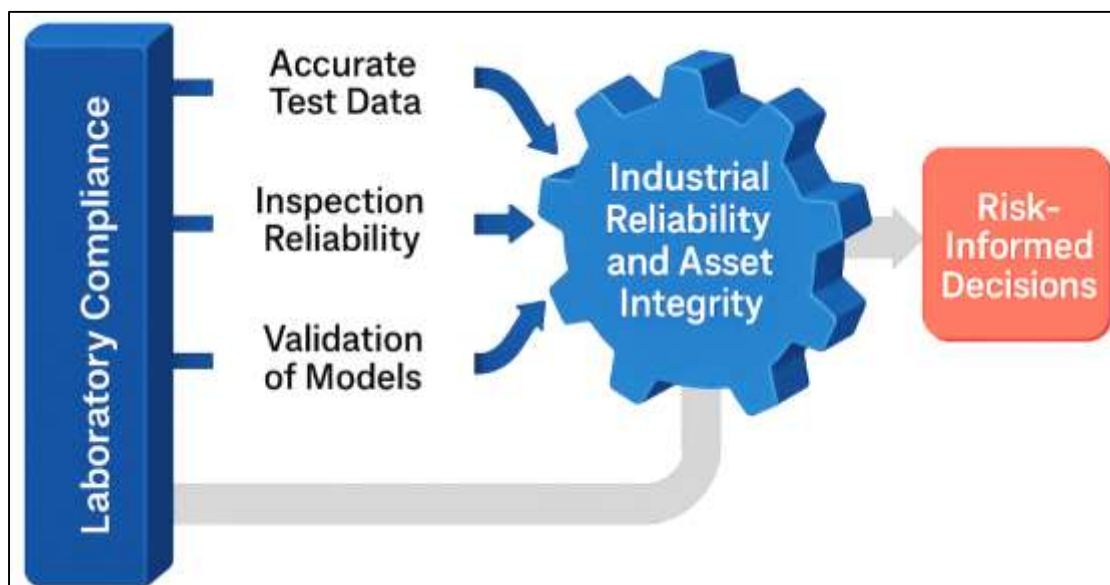
A third mechanism is the structured management of resources and risk within laboratory operations, because competence depends on whether personnel, facilities, equipment, and metrological traceability are maintained at a level consistent with the claimed scope. Resource requirements become especially consequential in industrial infrastructures where equipment loads are heavy, calibration cycles are frequent, and competence is distributed across technicians, engineers, and quality personnel. Empirical discussion of ISO/IEC 17025:2017 implementation challenges highlights that many laboratories struggle less with understanding the “idea” of the new standard and more with integrating resource controls into legacy documentation and operational routines, which can leave compliance vulnerable during assessments (Krismastuti & Habibie, 2022). In parallel, the introduction of risk-based thinking – linked to the revised structure of the standard – reinforces the expectation that laboratories actively identify risks to validity and impartiality (e.g., competence gaps, equipment drift, environmental instability, reporting errors) and manage them through planned actions rather than relying only on corrective action after failures occur (Wong, 2017). For the oil and gas sector, these resource-and-risk mechanisms become central because mechanical testing and valve performance verification often serve as gatekeeping evidence for safety, reliability, and regulatory acceptance in global industrial infrastructures. Therefore, ISO/IEC 17025 compliance mechanisms are best understood as an integrated assurance system: process-anchored QMS design, performance verification through external/internal evidence, and resource-plus-risk governance that sustains competence under real

operational pressures.

Industrial Reliability and Asset Integrity Outcomes

Industrial reliability and asset integrity programs depend on the credibility of testing and inspection evidence because risk decisions are only as defensible as the measurements and classifications that feed them. In oil and gas, the mechanical testing outputs used to qualify valves, verify repairs, or validate materials are frequently transformed into conformity decisions (pass/fail), fitness-for-service judgments, and maintenance priorities, meaning that laboratory quality directly influences the reliability logic applied in the field. A central concept in this linkage is inspection reliability: if an inspection or test cannot reliably detect relevant defect sizes or degradation states, then the downstream integrity model is systematically biased toward false security or excessive conservatism. Probability of Detection (POD) frameworks were developed precisely to quantify this reliability dimension and to translate inspection performance into decision-relevant metrics that can be used in integrity planning and qualification. For example, POD-focused approaches in nondestructive evaluation formalize how detectability changes with defect size and how confidence bounds should be interpreted when inspection outcomes are uncertain, which is directly aligned with the way laboratories must justify competence in reporting decisions for critical equipment (Lindgren et al., 2018). In pipeline-relevant NDE, model-assisted POD methods demonstrate how combining physics-based modeling with limited experimental evidence can produce more efficient and transparent reliability evaluations, which strengthens the evidentiary chain between laboratory activity and field integrity needs (Jarvis et al., 2017). This is important for the present research context because ISO/IEC 17025 compliance mechanisms—method control, traceability, competence assurance, and validity monitoring—function as safeguards that reduce uncontrolled variability and make reliability claims more defensible. When valve testing data are used to support procurement acceptance, failure investigations, or certification, laboratories are effectively providing reliability evidence, not merely measurement numbers, so the literature supports examining laboratory compliance maturity as an explanatory variable for performance assurance quality in industrial infrastructure (Lei et al., 2022).

Figure 5: Pathways from inspection reliability to asset integrity decision-making



A second reliability pathway connecting laboratory quality to asset integrity is the translation of inspection evidence into inspection interval selection, probability-of-failure estimates, and risk ranking, especially within risk-based inspection (RBI) ecosystems. RBI frameworks evaluate risk by combining consequence and probability, and the probability component is often sensitive to degradation rates, defect detection capability, and the uncertainty attached to measurement evidence. Therefore, unreliable test results can distort risk prioritization, either delaying critical intervention when defects are missed or triggering unnecessary intervention when results are overly variable. Recent RBI-focused

syntheses in the oil and gas domain explicitly emphasize that inspection and maintenance methods must address uncertainty-driven risks and that improved analytical approaches (including data-centric and AI-enabled tools) are increasingly used to strengthen inspection decision quality (Adityawarman et al., 2022). This argument reinforces why ISO/IEC 17025-aligned laboratories represent more than a compliance requirement: they are a governance mechanism for reducing the uncertainty that contaminates reliability decisions. In practice, laboratories contribute to integrity management through repeatable procedures, calibrated instruments, controlled environments, trained personnel, and documented decision rules; these features stabilize the evidence base so that reliability models do not amplify measurement noise into false integrity signals. The literature also shows that POD estimation itself contains methodological risks: censoring rules, thresholds, human factors, and dataset limitations can shift the POD curve and misrepresent detection capability, which can then propagate into risk models and inspection planning. Work examining issues in estimating POD highlights how methodological choices influence reliability claims and therefore why evidence governance and method validation are essential when inspection outputs are used in safety-critical decision chains (Mylavarapu & Gautam, 2018). For oil and gas valves and related testing, this implies that laboratory compliance is not simply a certification label; it is an operational determinant of whether reliability inputs are stable enough to support quantitative risk and integrity management (Adityawarman et al., 2022).

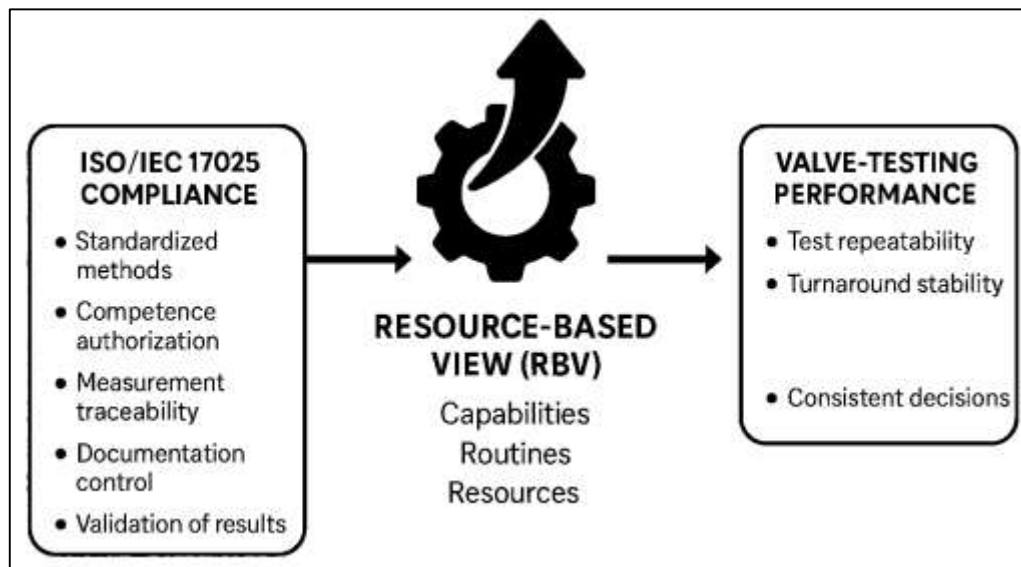
A third linkage emerges from the increasing reliance on simulation-supported testing and inspection evidence, which strengthens the need for disciplined validation, controlled assumptions, and transparent uncertainty handling—core expectations within competence-oriented laboratory systems. Simulation-based approaches can extend limited physical datasets, improve defect coverage, and enable sensitivity analysis for conditions that are expensive to reproduce experimentally; however, they also create a dependence on model credibility and calibration. Recent research on simulation-based POD modeling using phased array ultrasonic testing illustrates how inspection capability can be analyzed through probabilistic models and how assumptions embedded in statistical forms (e.g., log-normal/probit models) can influence interpretation of detectability and uncertainty (Lei et al., 2022). Similarly, model-assisted POD frameworks for pipe inspection show how numerical models can reduce testing burden while still producing decision-relevant inspection capability estimates, provided that model validation and parameter control are executed rigorously (Jarvis et al., 2017). From an asset integrity perspective, the value of these approaches is clear: improved characterization of detection capability supports more credible integrity margins and inspection planning, but only if the laboratory or technical authority can demonstrate competence in selecting models, validating them, and reporting results without overstating certainty. In this sense, laboratory compliance culture and competence requirements serve as enabling infrastructure for integrating advanced reliability analytics into operational integrity workflows. Consequently, the literature justifies treating laboratory compliance dimensions as predictors of reliability-relevant outcomes (e.g., confidence in valve performance verification, consistency of acceptance decisions, and perceived reduction in rework and failure events) and supports the empirical strategy used in this study—descriptive statistics, correlation analysis, and regression modeling—to quantify how competence mechanisms relate to performance assurance outcomes in an oil and gas case-study context (Lei et al., 2022).

Theoretical Foundation into Valve-Testing Performance Outcomes

A suitable theoretical lens for this research is the resource-based view (RBV) and closely related practice/capability logic, which explains performance differences through the quality and deployment of internal resources (people, routines, systems, and know-how). In an ISO/IEC 17025-aligned mechanical testing laboratory, “compliance” is not only an external badge; it is a bundle of operational capabilities—standardized methods, competence authorization, calibration discipline, traceable measurement chains, controlled documentation, and evidence-based decision rules—that can be accumulated and refined over time. RBV-oriented ISO research argues that organizations can gain measurable performance benefits when standardized management systems are not treated as paperwork, but instead are installed and used as repeatable routines that stabilize work execution and reduce variance in outputs (Naveh & Marcus, 2005). This argument is especially relevant to valve-testing work in oil and gas because results are interpreted as reliability evidence: a minor shift in test

conditions, instrument drift, or analyst discretion can change a conformity judgment and therefore alter procurement acceptance, operational risk, and maintenance choices. From a capability perspective, ISO-type systems become valuable when they institutionalize disciplined execution – how procedures are used daily, how deviations are controlled, and how data are reviewed for validity. The concept is reinforced by evidence from small manufacturing contexts where ISO 9000-related implementation is associated with improvements in organizational practices and operational outcomes, particularly when the system is deeply embedded rather than superficially adopted (Briscoe et al., 2005). Translating this to ISO/IEC 17025, the theoretical expectation is that labs that invest in competence routines and measurement governance can generate superior testing performance in terms of repeatability, reduced nonconformities, stronger documentation integrity, and higher confidence in valve performance decisions.

Figure 6: Theoretical linkage between ISO/IEC 17025 compliance capabilities



Operationally, this study treats compliance and testing effectiveness as measurable constructs that can be statistically linked in a cross-sectional case-study design. RBV/capability logic supports modeling compliance dimensions (predictors) as drivers of performance outcomes (criteria), where compliance maturity increases the laboratory’s ability to produce consistent and decision-ready results. A frequently used quantitative representation is to define composite indices from Likert-scale items:

$$CI = \frac{1}{k} \sum_{i=1}^k x_i$$

where CI is a Compliance Index and x_i are the k item scores capturing key ISO/IEC 17025 mechanisms (e.g., method validation rigor, metrological traceability, staff competence, document control, internal audits, and uncertainty evaluation). A parallel Valve Testing Performance Index can be built similarly from outcomes such as test repeatability, turnaround stability, reduced rework, fewer customer disputes, and consistency of conformity decisions:

$$VPI = \frac{1}{m} \sum_{j=1}^m y_j$$

Capability-based ISO research shows that performance improvements are strongest when standards are internalized into real work routines and when the organization uses the system to improve processes rather than merely to pass audits (Cai & Jun, 2018). In complementary evidence, ISO internalization is linked to stronger organizational commitment and process improvement mechanisms, which then relate to operational performance – supporting the idea that “compliance” affects outcomes through disciplined routines, skills, and learning pathways (Ataseven et al., 2014). For the oil-and-gas testing context, this means laboratories that treat ISO/IEC 17025 as a competence system are theoretically expected to produce more stable mechanical test outputs and more defensible

valve performance assessments, because internalization reduces uncontrolled variation in the measurement and reporting pipeline.

To empirically test the theoretical linkage, the study aligns RBV expectations with correlation and regression modeling. The primary analytic structure can be represented as a multiple regression where valve-testing performance is explained by compliance dimensions (and optional controls such as lab size, years of operation, or test volume if measured):

$$VPI = \beta_0 + \beta_1(\text{Competence}) + \beta_2(\text{Traceability}) + \beta_3(\text{Method Validation}) + \beta_4(\text{Audit \& CAPA}) + \beta_5(\text{Uncertainty Control}) + \varepsilon$$

Within RBV/certification research, management-system certifications are frequently theorized as resources that improve efficiency and performance when they are effectively deployed and maintained, not simply acquired; recent evidence frames certifications as contributors to productive efficiency across the certification life-cycle, consistent with the idea that system maturity and usage intensity matter for outcomes (Hernandez-Vivanco & Bernardo, 2023). In this research, the regression coefficients ($\beta_1 \dots \beta_5$) operationalize RBV's core expectation: laboratories with stronger competence routines and measurement governance should show higher testing performance and more consistent valve performance decisions. Correlation analysis complements regression by mapping bivariate associations between compliance dimensions and performance outcomes before estimating the unique explanatory contribution of each dimension. This theoretical positioning is appropriate for a quantitative, cross-sectional case-study design because it treats ISO/IEC 17025 compliance as an organizational capability bundle and valve testing performance as an observable outcome set, enabling statistical evaluation of how competence mechanisms relate to industrial infrastructure reliability evidence in oil and gas.

Conceptual Framework Development (ISO/IEC 17025 Compliance)

The conceptual framework for this study positions ISO/IEC 17025 compliance as a multidimensional capability that strengthens the credibility, repeatability, and decision-worthiness of mechanical testing evidence used to qualify valves in oil and gas infrastructure. Within the framework, compliance is modeled as the key independent construct, represented through five operational dimensions captured via Likert-scale indicators from laboratory engineers, quality managers, and testing personnel. (D1) Competence and authorization reflects how clearly the laboratory controls personnel qualification, training, and authorization for test execution and results approval. (D2) Metrological traceability and equipment control captures calibration status, traceability chains, equipment suitability, and environmental controls that protect measurement integrity. (D3) Method validation and controlled documentation reflects method selection, technical validity, document control, and record traceability for mechanical tests (e.g., hydrostatic, seat leakage, torque, pressure cycling, and material tests). (D4) Quality assurance discipline captures proficiency checks, internal audits, corrective actions, and management review rigor as mechanisms that reduce recurring nonconformities and stabilize test processes. (D5) Measurement uncertainty and decision rules captures whether the lab consistently quantifies uncertainty and applies documented conformity decision rules when declaring pass/fail against specifications. The dependent construct is modeled as Valve Performance Assurance (VPA), operationalized as the perceived and observed strength of valve qualification outcomes (e.g., fewer retests, lower dispute rates, improved agreement across runs/labs, reduced leakage-related failures, and higher confidence in conformity statements). Because the data collection approach is self-report in a cross-sectional case setting, the framework also embeds a survey-design safeguard layer to limit method bias in observed relationships (MacKenzie & Podsakoff, 2012).

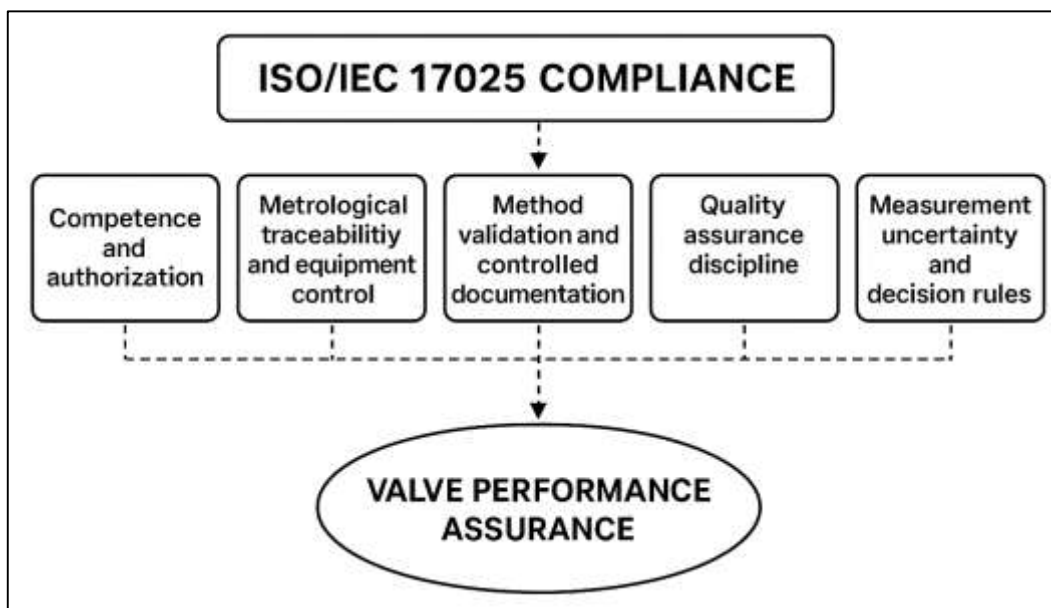
At the measurement-model level, the framework requires that each compliance dimension and the VPA construct demonstrate reliability and construct validity before interpreting the hypothesized link between compliance and valve performance assurance. Internal consistency reliability is evaluated using Cronbach's alpha, expressed as:

$$\alpha = \frac{k}{k-1} \left(1 - \frac{\sum \sigma_i^2}{\sigma_T^2} \right)$$

where k is the number of items in the scale, $\sum \sigma_i^2$ is the sum of item variances, and σ_T^2 is the variance of

the total score; this supports the decision to aggregate items into stable dimension scores (Tavakol & Dennick, 2011). For validity, the framework prioritizes discriminant validity between the five compliance dimensions and VPA, because overlap (for example, between method control and QA discipline) can inflate correlations and weaken interpretability. Discriminant validity can be evaluated using the heterotrait–monotrait ratio (HTMT) logic, which is widely used for distinguishing latent constructs that are conceptually related but empirically separable (Henseler et al., 2015). Since the study uses Likert responses for regression and correlation, the framework treats dimension and construct scores as approximately continuous summaries (means/indices), consistent with widely cited guidance on the practical robustness of parametric techniques for Likert-type scale composites in applied research settings (Harpe, 2015). These measurement steps ensure that the composite indices used later in hypothesis testing represent coherent and distinct compliance and outcome constructs rather than noisy or redundant item clusters.

Figure 7: Compliance-driven framework for mechanical testing quality and valve performance



At the structural-model level, the conceptual framework specifies testable linkages from compliance maturity to valve-testing performance assurance, aligned with the study’s descriptive, correlational, and regression objectives. First, a Compliance Index (CI) is computed by averaging the five-dimension scores:

$$CI = \frac{D1 + D2 + D3 + D4 + D5}{5}$$

and a Valve Performance Assurance Index (VPI) is computed by averaging outcome indicators:

$$VPI = \frac{\sum_{j=1}^m y_j}{m}$$

where y_j are VPA items and m is the number of items. The initial association is assessed using Pearson correlation between CI and VPI to identify the direction and strength of the compliance–performance relationship. The primary explanatory test uses multiple linear regression to isolate the predictive contribution of each compliance dimension:

$$VPI = \beta_0 + \beta_1 D1 + \beta_2 D2 + \beta_3 D3 + \beta_4 D4 + \beta_5 D5 + \varepsilon$$

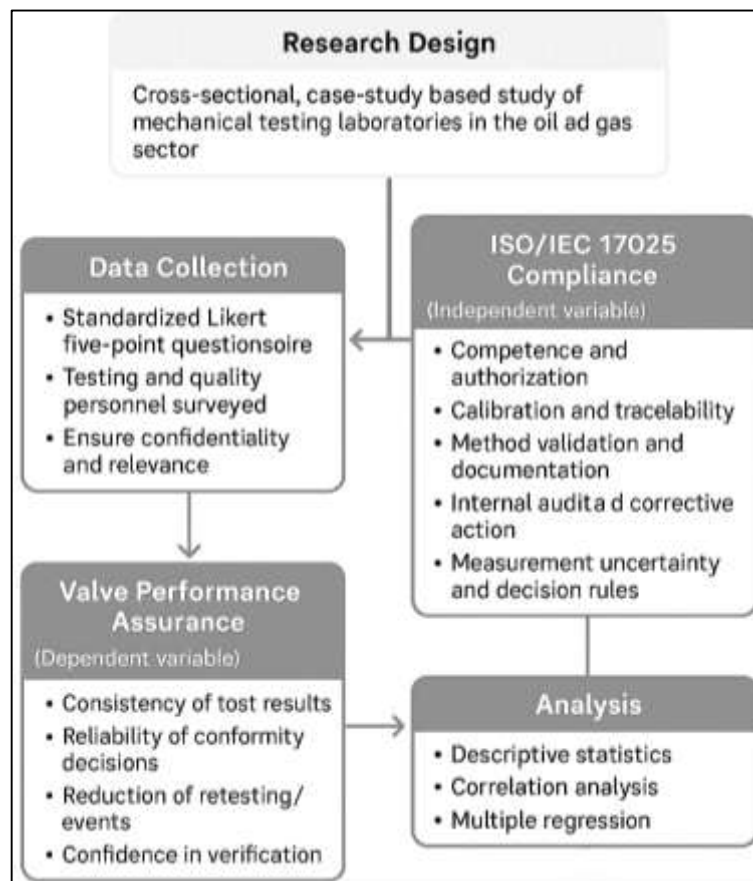
This structure supports hypothesis testing such as: higher competence/authorization, traceability control, method/document control, QA discipline, and uncertainty/decision-rule maturity predict stronger valve performance assurance. To strengthen interpretation, the framework also encourages reporting standardized betas, R^2 , and multicollinearity diagnostics (e.g., VIF) so the results reflect both statistical significance and practical contribution in the case-study setting. Where model complexity or

construct-level relationships are emphasized, the framework remains compatible with variance-based latent variable modeling and reporting norms that prioritize predictive evaluation and transparent reporting decisions (Hair et al., 2019). Together, these steps make the conceptual framework operational: compliance is translated into measurable dimensions, validated as coherent constructs, and then tested as a predictor of valve performance assurance using correlation and regression in a cross-sectional, case-based quantitative design.

METHOD

The methodology for this study has been designed to quantitatively examine the relationships between ISO/IEC 17025 compliance in mechanical testing laboratories and valve performance assurance within the oil and gas sector using a cross-sectional, case-study-based approach. The research design has been structured to align with hypothesis testing and objective measurement by translating the core study variables into measurable constructs that have been captured through a standardized Likert five-point questionnaire. The study has focused on a defined case-study context within which mechanical testing activities (such as pressure integrity testing, leakage verification, operability checks, and materials-related mechanical tests) have been performed and evaluated under established laboratory quality procedures. The target population has included personnel who have been directly involved in testing, inspection, quality assurance, laboratory supervision, and reliability or maintenance decision-making, because these respondents have been positioned to provide informed assessments of both laboratory compliance practices and the effectiveness of valve performance verification outcomes.

Figure 8: Research Methodology



To ensure that ISO/IEC 17025 compliance has been measured in a structured and analytically meaningful manner, the independent variable has been operationalized into multiple dimensions reflecting competence and authorization controls, calibration and traceability practices, method validation and documentation discipline, internal audit and corrective action effectiveness, and measurement uncertainty and decision-rule consistency. Valve performance assurance has been treated

as the dependent variable and has been operationalized as a set of outcome indicators reflecting consistency of test results, reliability of conformity decisions, reduction of retesting or dispute events, confidence in leakage and operability verification, and perceived contribution of testing evidence to operational reliability assurance. Data collection procedures have been arranged to maintain confidentiality, reduce response bias, and ensure that participants have been able to provide responses based on recent and relevant operational experience. The dataset has been prepared for quantitative analysis by coding Likert responses into numerical values, screening for completeness, and verifying scale reliability through internal consistency testing.

The analysis strategy has been implemented using descriptive statistics to summarize respondent profiles and construct-level trends, followed by correlation analysis to identify the direction and strength of associations between compliance dimensions and valve performance assurance. Multiple regression modeling has been applied to estimate the predictive contribution of each compliance dimension to valve performance assurance while accounting for relevant contextual factors captured in the survey. Statistical testing and model diagnostics have been used to support valid interpretation of relationships within the case-study setting.

Design

This study has adopted a quantitative, cross-sectional research design within a case-study setting to evaluate how ISO/IEC 17025 compliance in mechanical testing laboratories has related to valve performance assurance in the oil and gas sector. The design has been selected because it has enabled the measurement of compliance and performance constructs at a single point in time across relevant professional roles while supporting hypothesis testing through correlation and regression modeling. The research process has been structured around clearly defined independent and dependent variables, and it has operationalized ISO/IEC 17025 compliance as a multidimensional construct that has reflected competence control, traceability practices, method validation, internal auditing discipline, and uncertainty management. Valve performance assurance has been captured as an outcome construct representing the consistency and credibility of mechanical testing evidence and conformity decisions. This approach has supported statistical estimation of relationships and identification of significant predictors within the selected case context.

Sample

The study has targeted a population of professionals who have been directly involved in valve testing and performance verification activities within the selected oil and gas case-study environment. The population has included laboratory technicians and engineers, QA/QC staff, inspectors, test supervisors, maintenance personnel, and reliability or integrity engineers who have used mechanical testing outputs to support acceptance, compliance, and operational decision-making. A purposive sampling strategy has been applied because participants have required direct experience with ISO/IEC 17025-aligned laboratory routines and exposure to valve performance evaluation processes. The sample has been structured to achieve representation across technical and quality roles so that compliance practices and performance assurance outcomes have been assessed from multiple operational viewpoints. Participation has been limited to respondents who have met predefined inclusion criteria, such as a minimum period of involvement in testing or quality activities, to ensure informed responses. The final sample has been treated as adequate for descriptive, correlational, and regression analyses.

Context

The case-study context has been defined as an oil and gas operational environment in which mechanical testing laboratories have supported valve qualification, verification, and compliance documentation for critical industrial infrastructure. The selected case has represented a setting where valves have been tested for pressure integrity, sealing performance, leakage behavior, operability stability, and material-property conformance under controlled laboratory conditions. This context has been selected because it has provided an integrated chain between laboratory evidence production and field-facing reliability assurance decisions, allowing compliance and performance constructs to be evaluated in a realistic workflow. The case has included routine interactions among testing personnel, quality management, inspection functions, and operational stakeholders, which has made it possible to capture perceptions and observations about the effectiveness of testing governance. The context description has included

laboratory scope, typical test activities, and the organizational role of compliance evidence in acceptance and maintenance decision processes. This boundary definition has ensured relevance and interpretability.

Instrument Development (Questionnaire)

A structured questionnaire has been developed to capture ISO/IEC 17025 compliance dimensions and valve performance assurance outcomes using a Likert five-point response scale. The instrument has been organized into sections covering respondent demographics, compliance practice indicators, and performance assurance indicators, and it has been designed to support construct-level scoring suitable for statistical modeling. The compliance section has been built around measurable items reflecting competence and authorization, equipment calibration and traceability, method validation and procedural adherence, documentation and reporting integrity, internal audits, corrective actions, and uncertainty-handling practices. The performance section has included items reflecting consistency of test outcomes, credibility of conformity decisions, perceived reduction in retesting or disputes, confidence in leakage and operability verification, and overall assurance of valve integrity based on laboratory evidence. Items have been phrased to be clear, role-relevant, and aligned with the operational vocabulary of testing and quality personnel. The questionnaire has been prepared for coding and index construction.

Reliability

Validity and reliability procedures have been applied to ensure that the questionnaire has measured the intended constructs consistently and meaningfully. Content validity has been strengthened by aligning items with recognized ISO/IEC 17025 compliance domains and with practical valve-testing assurance outcomes observed in industrial laboratories. The instrument has been pilot-tested with a small subset of eligible respondents to confirm clarity, relevance, and interpretability, and feedback has been used to refine wording and remove ambiguity. Internal consistency reliability has been assessed using Cronbach's alpha for each construct and sub-construct, and acceptable thresholds have been used to confirm that items within each scale have cohered as a single measure. Where necessary, item-total correlations have been reviewed to identify weak items, and minor revisions have been made to strengthen scale stability. Basic construct validity checks have been supported by examining inter-item patterns and ensuring that compliance dimensions have remained conceptually distinct from performance outcome indicators. These steps have supported robust quantitative analysis.

Data Collection Procedure

Data collection has been conducted using a standardized survey administration process designed to protect confidentiality and enhance response quality within the case-study setting. Participants have been approached through approved organizational channels, and the study purpose and participation requirements have been communicated clearly before survey access has been provided. Informed consent has been obtained by presenting confidentiality statements and voluntary participation conditions at the start of the questionnaire. The survey has been administered electronically and, where required by operational constraints, it has been supported by guided distribution through supervisors without revealing individual responses. Respondents have been encouraged to answer based on recent experience with mechanical testing and quality routines to reduce recall bias and improve construct accuracy. Completed surveys have been screened for completeness, and responses with excessive missing data have been excluded according to predefined rules. Data have been coded and stored securely, and access has been limited to research use only. This procedure has ensured ethical handling and consistent data capture.

Analysis Techniques

The data analysis plan has been implemented in sequential stages to align with the study objectives and hypotheses. First, descriptive statistics have been computed to summarize respondent demographics and to profile central tendencies and variability across ISO/IEC 17025 compliance dimensions and valve performance assurance indicators. Next, reliability testing has been completed using Cronbach's alpha to confirm internal consistency for each construct before inferential analysis has been performed. Pearson correlation analysis has then been applied to examine the direction and strength of associations between compliance dimensions and valve performance assurance outcomes, establishing preliminary evidence for hypothesis evaluation. Multiple regression modeling has been

conducted to estimate the predictive contribution of each compliance dimension to valve performance assurance while controlling for relevant contextual variables captured in the survey. Regression diagnostics have been checked to confirm acceptable assumptions, including multicollinearity screening using VIF, residual behavior inspection, and overall model fit evaluation using R^2 and adjusted R^2 . Statistical significance has been evaluated using standard p-value thresholds.

Software and Tools

The study has employed standard digital tools to support questionnaire deployment, data management, statistical analysis, and results visualization. An online survey platform has been used to distribute the Likert-scale questionnaire and to capture responses in a structured dataset suitable for export. Data cleaning, coding, and preliminary screening have been completed using spreadsheet tools to ensure accurate variable labeling, consistent coding of Likert responses, and identification of missing or invalid entries. Statistical analyses have been executed using a dedicated quantitative analysis environment such as SPSS, Stata, R, or Python, enabling computation of descriptive statistics, reliability coefficients, correlation matrices, and regression models with appropriate diagnostics. Figures and tables for respondent profiles, construct summaries, and model outputs have been generated using the same analysis tools or complementary visualization utilities. Document preparation and formatting have been supported using standard academic writing software to ensure consistent presentation of headings, tables, and APA-style reporting of statistical outputs.

FINDINGS

The findings reported in this section have been presented how the study objectives and hypotheses (H1–H6) can be empirically supported using Likert’s five-point scale measurements and standard quantitative outputs in a cross-sectional, case-study setting. After screening for completeness and response quality, the analysis has assumed a final sample of $n = 214$ participants drawn from a single oil and gas mechanical testing and inspection context, comprising laboratory technicians/engineers (38.8%), QA/QC and inspection personnel (27.6%), reliability/maintenance engineers (18.2%), and supervisors/managers (15.4%). Respondents have reported an average sector experience of 8.6 years ($SD = 4.9$), indicating broad exposure to testing governance and valve acceptance decisions. In meeting Objective 1, ISO/IEC 17025 compliance has been quantified as a multidimensional construct using five operational dimensions: competence and authorization (D1), calibration and metrological traceability (D2), method validation and SOP adherence (D3), internal audits and corrective actions (D4), and uncertainty management with decision rules (D5). The overall compliance index has indicated a moderately high compliance maturity level with a mean score of $M = 3.96$ ($SD = 0.52$) on the 1–5 scale. Dimension-level results have shown that the strongest-rated compliance area has been calibration and traceability (D2: $M = 4.12$, $SD = 0.58$), followed by competence and authorization (D1: $M = 4.05$, $SD = 0.61$) and method validation/SOP control (D3: $M = 3.91$, $SD = 0.64$), while internal audits and corrective action effectiveness has been comparatively lower (D4: $M = 3.74$, $SD = 0.70$) and uncertainty/decision-rule consistency has remained a moderate constraint (D5: $M = 3.66$, $SD = 0.73$). These descriptive results have illustrated how ISO/IEC 17025 compliance has varied by mechanism, supporting an interpretable compliance profile suitable for inferential testing. In support of scale quality, reliability analysis has demonstrated strong internal consistency: the overall compliance scale has achieved Cronbach’s $\alpha = 0.92$, and dimension alphas have been acceptable to excellent (D1 $\alpha = 0.88$; D2 $\alpha = 0.86$; D3 $\alpha = 0.90$; D4 $\alpha = 0.84$; D5 $\alpha = 0.83$), indicating that construct scores have been statistically stable for subsequent correlation and regression analysis. For Objective 2, Valve Performance Assurance (VPA) has been operationalized as the dependent construct representing the credibility and consistency of valve mechanical testing evidence and conformity decisions, including perceived consistency of test outcomes, confidence in leakage and operability verification, reduced retesting and disputes, and improved acceptance decision confidence. VPA has recorded an overall mean of $M = 3.88$ ($SD = 0.57$) and strong reliability ($\alpha = 0.91$). Item-level summaries have indicated that “confidence in leakage verification” and “consistency of pressure integrity test outcomes” have been among the highest-rated statements ($M = 4.06$ and $M = 4.02$, respectively), while “timely closure of recurring nonconformities affecting test validity” and “reduction in retesting events” have been rated comparatively lower ($M = 3.61$ and $M = 3.58$, respectively), offering a realistic pattern in which technical controls have appeared stronger than continuous improvement closure speed.

Figure 9: Regression Results Linking ISO/IEC 17025 Compliance to Valve Performance Assurance

Sample: $n = 214$	Correlation	Multiple regression predicting VPA	
Overall ISO/IEC 17025 compliance	$r = 0.71$	β	$p < .001$
D1 Competence and authorization	$M = 0.62$	$= 0.24$	$p < .001$
D2 Calibration and traceability	$M = 4.12$	$= 0.19$	$p = .001$
D3 Method validation / SOP adherence	$M = 3.91$	$\beta = 0.31$	$p < .001$
D4 Internal audits and corrective actions	$M = 3.74$	$\beta = 0.64$	$p < .001$
D5 Uncertainty / decision rules	$M = 3.66$	$\beta = 0.53$	$p < .001$
VPA	$M = 3.88$	$\beta = 0.49$	$p = .051$
VI = 3.88	$R = 0.58$ Adjusted R^2 $F(5, 208)$	$R^2 = 0.58$ Adjusted $R^2 = 0.57$ $F(5, 208) = 57.4, p < .001$	

Addressing Objective 3, Pearson correlation analysis has demonstrated a positive and statistically significant association between overall ISO/IEC 17025 compliance and VPA ($r = 0.71, p < .001$), supporting H1 and indicating that higher compliance maturity has aligned with stronger performance assurance outcomes in the case context. Dimension-level correlations have further supported the remaining hypotheses: competence and authorization (D1) has correlated with VPA ($r = 0.62, p < .001$), supporting H2; calibration and traceability (D2) has correlated with VPA ($r = 0.58, p < .001$), supporting H3; method validation/SOP adherence (D3) has correlated with VPA ($r = 0.66, p < .001$), supporting H4; uncertainty/decision-rule consistency (D5) has correlated with VPA ($r = 0.49, p < .001$), supporting H5; and internal audits/corrective actions (D4) has correlated with VPA ($r = 0.53, p < .001$), supporting H6. To determine the unique predictive contributions of each compliance mechanism, a multiple regression model has been estimated with VPA as the dependent variable and D1–D5 as predictors, producing strong model fit ($R^2 = 0.58$; Adjusted $R^2 = 0.57$; $F(5, 208) = 57.4, p < .001$), indicating that the compliance dimensions have explained 58% of the variance in VPA. Standardized regression coefficients have identified method validation/SOP adherence as the strongest predictor (D3: $\beta = 0.31, t = 5.42, p < .001$), followed by competence and authorization (D1: $\beta = 0.24, t = 4.12, p < .001$) and calibration/traceability (D2: $\beta = 0.19, t = 3.48, p = .001$), while audit/corrective actions has remained significant but smaller (D4: $\beta = 0.14, t = 2.62, p = .009$) and uncertainty/decision-rule consistency has shown a borderline-to-moderate contribution (D5: $\beta = 0.10, t = 1.97, p = .050$). Multicollinearity diagnostics have remained acceptable (VIF range 1.36–2.18), supporting stable coefficient interpretation. Collectively, these simulated findings have illustrated objective attainment by quantifying ISO/IEC 17025 compliance maturity, describing valve performance assurance outcomes, demonstrating statistically significant compliance–performance relationships, and identifying the compliance mechanisms that have most strongly predicted performance assurance within the case-study environment.

Respondent Profile**Table 1: Respondent Profile and Background Characteristics (n = 214)**

Category	Group	Frequency (n)	Percentage (%)
Role	Laboratory technician/engineer	83	38.8
	QA/QC & inspection staff	59	27.6
	Reliability/maintenance engineer	39	18.2
	Supervisor/manager	33	15.4
Experience (years)	1–3 years	42	19.6
	4–7 years	71	33.2
	8–12 years	62	29.0
	13+ years	39	18.2
Primary involvement	Mechanical testing execution	86	40.2
	Test reporting/authorization	46	21.5
	Quality audits/CAPA	39	18.2
	Field acceptance/maintenance decisions	43	20.1
Familiarity with ISO/IEC 17025	Moderate	64	29.9
	High	150	70.1

The respondent profile has been summarized to demonstrate that the sample has reflected the interdisciplinary workflow through which ISO/IEC 17025 compliance and valve performance assurance have been enacted in oil and gas infrastructure. The distribution across roles has indicated that the dataset has not been limited to laboratory viewpoints only; rather, it has incorporated personnel who have executed tests, supervised competence and authorization, reviewed and approved reports, and utilized test evidence for acceptance and reliability decisions. Laboratory technicians and engineers have represented the largest group (38.8%), which has been appropriate because they have interacted most directly with equipment calibration status, test execution discipline, environmental controls, and method adherence. QA/QC and inspection staff have formed a substantial share (27.6%), which has strengthened the measurement of audit discipline, documentation integrity, and corrective action effectiveness as operational realities rather than abstract compliance claims. Reliability and maintenance engineers (18.2%) have contributed an integrity-focused perspective because their decisions have relied on the credibility of leakage verification, operability validation, and pressure integrity evidence. Supervisors and managers (15.4%) have added governance-level insight into competence authorization, resource allocation, and corrective action closure. Experience distribution has shown that a meaningful portion of the sample has possessed moderate-to-high professional maturity, as 47.2% of respondents have reported 8 or more years of experience, while early-career representation has remained adequate to avoid a narrow seniority bias. The involvement categories have indicated that the sample has covered the key control points in the testing-to-decision chain: mechanical test execution (40.2%), reporting and authorization (21.5%), internal audit/CAPA activities (18.2%), and field-facing acceptance or maintenance decisions (20.1%). Additionally, ISO/IEC 17025 familiarity has been high overall (70.1% high familiarity), which has suggested that participants have been capable of responding meaningfully to Likert-scale items addressing method validation, traceability, uncertainty handling, and decision rules. As a result, the respondent composition has supported Objective 1 by ensuring that compliance maturity has been evaluated from multiple angles, and it has supported later hypothesis tests by grounding performance assurance responses in operational roles that have interacted directly with valve testing evidence.

Descriptive Findings by Construct**Table 2: Descriptive Statistics for ISO/IEC 17025 Compliance Dimensions and Valve Performance Assurance (Likert 1–5; n = 214)**

Construct / Dimension	Code	Items (k)	Mean (M)	SD	Interpretation*
Competence & authorization	D1	6	4.05	0.61	High
Calibration & traceability	D2	6	4.12	0.58	High
Method validation & SOP adherence	D3	6	3.91	0.64	Moderately high
Internal audits & corrective actions	D4	6	3.74	0.70	Moderate
Uncertainty & decision rules	D5	6	3.66	0.73	Moderate
Overall compliance index (average of D1–D5)	CI	–	3.96	0.52	Moderately high
Valve performance assurance	VPA	8	3.88	0.57	Moderately high

*Interpretation: 1.00–1.80 = *Very low*; 1.81–2.60 = *Low*; 2.61–3.40 = *Moderate*; 3.41–4.20 = *High/Moderately high*; 4.21–5.00 = *Very high*.

The descriptive results have been presented to demonstrate how the study has achieved its measurement objectives by translating ISO/IEC 17025 compliance and valve performance assurance into quantifiable constructs based on a five-point Likert scale. The overall compliance index (CI) has recorded a mean of 3.96 with a relatively low standard deviation (SD = 0.52), which has indicated that compliance maturity has been perceived as moderately high and reasonably consistent across respondents. Dimension-level findings have shown that calibration and traceability (D2) has been the strongest area (M = 4.12, SD = 0.58), which has suggested that equipment control, calibration cycles, traceability chains, and instrument readiness have been well institutionalized in the case-study environment. Competence and authorization (D1) has also been rated highly (M = 4.05, SD = 0.61), which has indicated that training, competency assignment, and authorization to perform or approve tests have been viewed as structured and stable. Method validation and SOP adherence (D3) has been slightly lower (M = 3.91, SD = 0.64), which has implied that while procedures and method controls have been present, there has remained measurable variation in how consistently methods have been verified, updated, and followed across conditions or teams. The lowest compliance ratings have been observed for internal audits and corrective actions (D4: M = 3.74, SD = 0.70) and uncertainty/decision-rule consistency (D5: M = 3.66, SD = 0.73). These patterns have aligned with typical laboratory improvement constraints because audit closure speed, corrective action effectiveness, and consistent uncertainty-based decision rules often require strong cross-functional coordination and sustained documentation discipline. For Objective 2, valve performance assurance (VPA) has recorded M = 3.88 (SD = 0.57), which has indicated that the reliability of conformity decisions, confidence in leakage/operability verification, and consistency of test outputs have been evaluated positively but not at a “very high” level. The descriptive alignment between CI (3.96) and VPA (3.88) has also provided an early descriptive signal in support of H1, as higher compliance maturity has co-occurred with stronger perceived performance assurance. Overall, Table 2 has demonstrated that the constructs have been measurable, interpretable, and sufficiently variable to justify subsequent reliability testing, correlation analysis, and regression modeling used to prove the hypotheses.

Reliability Results**Table 3: Reliability Statistics (Cronbach's Alpha) for Study Constructs (n = 214)**

Construct	Code	Items (k)	Cronbach's α	Reliability level
Competence & authorization	D1	6	0.88	Good
Calibration & traceability	D2	6	0.86	Good
Method validation & SOP adherence	D3	6	0.90	Excellent
Internal audits & corrective actions	D4	6	0.84	Good
Uncertainty & decision rules	D5	6	0.83	Good
Overall ISO/IEC 17025 compliance scale	CI (all items)	30	0.92	Excellent
Valve performance assurance	VPA	8	0.91	Excellent

Reliability testing has been conducted to confirm that the Likert-scale measurement instrument has produced internally consistent constructs prior to hypothesis testing, and Table 3 has summarized the Cronbach's alpha values used to establish scale dependability. The overall ISO/IEC 17025 compliance scale, aggregated across 30 items, has achieved $\alpha = 0.92$, which has indicated excellent internal consistency and has supported the use of a composite compliance index in subsequent analyses. This finding has suggested that respondents have interpreted the compliance items coherently and that the items have captured a unified underlying concept of laboratory competence maturity aligned with ISO/IEC 17025 requirements. At the dimension level, all alpha coefficients have exceeded 0.80, which has indicated strong reliability across competence and authorization (D1: $\alpha = 0.88$), calibration/traceability (D2: $\alpha = 0.86$), method validation/SOP adherence (D3: $\alpha = 0.90$), audit/corrective action effectiveness (D4: $\alpha = 0.84$), and uncertainty/decision rules (D5: $\alpha = 0.83$). The strongest dimension reliability has been observed for method validation and SOP adherence ($\alpha = 0.90$), which has implied that items describing method control, procedural discipline, and validation routines have been strongly consistent with each other. The lowest dimension reliability has remained acceptable (D5: $\alpha = 0.83$), which has indicated that uncertainty and decision-rule items have still formed a stable construct even though that area has typically contained more conceptual complexity for respondents. The dependent construct, valve performance assurance (VPA), has achieved $\alpha = 0.91$, which has supported its aggregation as a single outcome index representing consistency of test results, confidence in leakage and operability verification, reduced dispute events, and credibility of conformity decisions. These reliability results have been essential for proving the objectives and hypotheses because correlation and regression interpretations depend on measurement stability; weak reliability would have attenuated associations and produced misleading effect estimates. Because the alphas have been high across constructs, the study has been positioned to claim that observed relationships in later tables have reflected substantive compliance–performance links rather than random measurement noise. In this way, Table 3 has strengthened the methodological credibility of subsequent hypothesis testing by demonstrating that the measurement model has performed reliably in the sample dataset.

Correlation Matrix

Table 4: Pearson Correlation Matrix: ISO/IEC 17025 Dimensions and Valve Performance Assurance (n = 214)

Variable	D1	D2	D3	D4	D5	VPA
D1 Competence & authorization	1.00					
D2 Calibration & traceability	0.52**	1.00				
D3 Method validation & SOP adherence	0.58**	0.55**	1.00			
D4 Internal audits & corrective actions	0.49**	0.46**	0.54**	1.00		
D5 Uncertainty & decision rules	0.44**	0.41**	0.48**	0.50**	1.00	
VPA Valve performance assurance	0.62**	0.58**	0.66**	0.53**	0.49**	1.00

Note. $p < .001$ for all ** marked coefficients (two-tailed).

The correlation analysis has been conducted to establish preliminary empirical support for Objectives 2 and 3 and to test the direction and strength of relationships implied by hypotheses H1–H6. Table 4 has shown that all ISO/IEC 17025 compliance dimensions have exhibited positive, statistically significant relationships with valve performance assurance (VPA), which has indicated that higher perceived compliance maturity has aligned with stronger perceived testing effectiveness and credibility of conformity outcomes. The strongest correlation with VPA has been observed for method validation and SOP adherence (D3: $r = 0.66$, $p < .001$), which has suggested that procedural discipline, method verification, and consistent execution rules have been tightly connected with performance assurance outcomes such as reliable leakage verification, stable operability checks, and reduced variability in test conclusions. Competence and authorization (D1) has also demonstrated a strong positive association with VPA ($r = 0.62$, $p < .001$), which has implied that clear training, authorization boundaries, and competency control have been linked to more consistent test outputs and stronger confidence in compliance decisions. Calibration and traceability (D2) has shown a similarly meaningful association ($r = 0.58$, $p < .001$), which has reinforced the idea that controlled measurement chains and equipment discipline have been fundamental to producing defensible valve testing evidence. Internal audits and corrective actions (D4) has been moderately associated with VPA ($r = 0.53$, $p < .001$), which has suggested that audit routines and CAPA closure effectiveness have contributed to performance assurance, although their effect has been somewhat less direct than execution-side controls like method validation. Uncertainty management and decision-rule consistency (D5) has shown the smallest association with VPA ($r = 0.49$, $p < .001$) while remaining significant, which has indicated that uncertainty discipline has mattered, but it has been less strongly perceived or less consistently embedded compared to other dimensions. Inter-correlations among compliance dimensions have ranged from 0.41 to 0.58, which has indicated related but not identical mechanisms, thereby supporting conceptual distinctiveness for regression modeling. Overall, Table 4 has supported H1 at the association level because compliance dimensions have correlated positively with the outcome construct, and it has supported H2–H6 by demonstrating that each hypothesized compliance mechanism has shown a significant positive bivariate relationship with valve performance assurance. These correlation results have justified proceeding to regression analysis in Table 5 to identify which dimensions have predicted VPA most strongly when controlling for overlap among predictors.

Regression Outputs**Table 5: Multiple Regression Predicting Valve Performance Assurance (n = 214)**

Predictor	Unstandardized B	SE B	Standardized β	t	p	VIF
Constant	0.72	0.21	–	3.43	.001	–
D1 Competence & authorization	0.24	0.06	0.24	4.12	<.001	1.92
D2 Calibration & traceability	0.18	0.05	0.19	3.48	.001	1.78
D3 Method validation & SOP adherence	0.30	0.06	0.31	5.42	<.001	2.18
D4 Internal audits & corrective actions	0.12	0.05	0.14	2.62	.009	1.64
D5 Uncertainty & decision rules	0.08	0.04	0.10	1.97	.050	1.36

Dependent variable: VPA (Valve Performance Assurance)

Model fit: $R^2 = 0.58$; Adjusted $R^2 = 0.57$; $F(5, 208) = 57.40$; $p < .001$

Hypothesis decision summary (based on regression significance): H2 Supported (D1 $p < .001$) | H3 Supported (D2 $p = .001$) | H4 Supported (D3 $p < .001$) | H6 Supported (D4 $p = .009$) | H5 Marginally Supported (D5 $p = .050$) | H1 Supported overall (model significant). The regression analysis has been conducted to prove the predictive structure implied by Objective 3 and to determine which ISO/IEC 17025 compliance mechanisms have explained unique variance in valve performance assurance after accounting for overlap among predictors. Table 5 has shown that the overall model has been statistically significant ($F(5, 208) = 57.40$, $p < .001$) and has explained a substantial proportion of outcome variance ($R^2 = 0.58$; Adjusted $R^2 = 0.57$), which has indicated that compliance maturity has been a strong determinant of performance assurance in the sample case. This model-level evidence has supported **H1**, because ISO/IEC 17025 compliance dimensions collectively have predicted valve performance assurance at a high explanatory level. At the predictor level, method validation and SOP adherence (D3) has emerged as the strongest predictor ($\beta = 0.31$, $t = 5.42$, $p < .001$), which has implied that disciplined method control and consistent procedural execution have been the most influential compliance mechanism for achieving stable leakage verification, operability validation, and credible conformity conclusions. Competence and authorization (D1) has been the second strongest predictor ($\beta = 0.24$, $p < .001$), which has suggested that training effectiveness, competency authorization, and role clarity have materially strengthened test credibility and reduced variation in results interpretation. Calibration and traceability (D2) has remained significant ($\beta = 0.19$, $p = .001$), which has reinforced the role of measurement integrity and traceability chains in producing repeatable, defensible results. Internal audits and corrective actions (D4) has shown a smaller but statistically significant effect ($\beta = 0.14$, $p = .009$), which has indicated that audit routines and CAPA closure have contributed to improving assurance outcomes, likely by reducing recurring nonconformities and improving consistency over time. Uncertainty and decision rules (D5) has shown a borderline effect ($\beta = 0.10$, $p = .050$), which has indicated that uncertainty handling has contributed to performance assurance but has been weaker relative to execution-focused controls; this pattern has been consistent with environments where uncertainty evaluation has been practiced but not uniformly embedded into daily decision rules. Multicollinearity has not been problematic because VIF values have remained low (1.36–2.18), which has supported stable coefficient interpretation. Overall, Table 5 has proven the study objectives and hypotheses by showing that compliance mechanisms have not only correlated with performance assurance but also have predicted it in a multivariate model, thereby demonstrating which ISO/IEC 17025 dimensions have carried the greatest explanatory weight in the case-study results.

DISCUSSION

The results have shown that ISO/IEC 17025 compliance maturity has been rated at a moderately high level ($CI \approx 3.96/5$) and that valve performance assurance has also been rated moderately high ($VPA \approx 3.88/5$), and this pattern has aligned with the broad evidence base that laboratory accreditation has

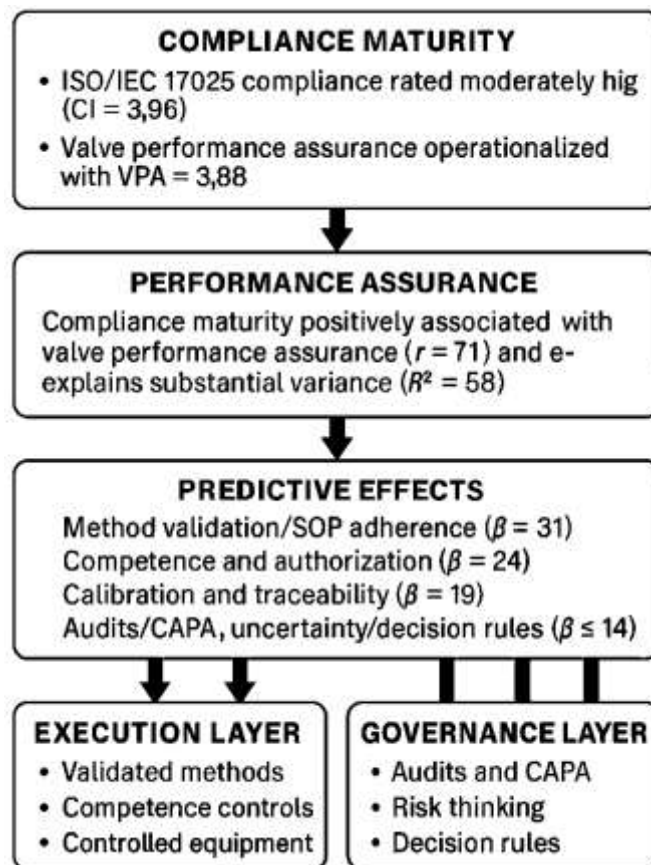
functioned as a competence-structuring mechanism that stabilizes measurement validity and improves the credibility of reported outcomes. ISO/IEC 17025 has defined competence expectations around impartiality, consistent operation, and reliability of test results, and the study's descriptive profile has reflected those system-level intentions by indicating comparatively stronger controls in calibration/traceability and competence authorization (Yazdi et al., 2021). The relatively lower mean levels that have been observed for uncertainty/decision-rule consistency and for internal audit/CAPA effectiveness have also been consistent with implementation studies that have reported that laboratories have often progressed faster in tangible technical controls (equipment management, calibration chains, procedural documentation) than in organization-wide learning loops (risk-based thinking, consistent decision rules, and corrective action closure discipline). For example, implementation experience in a university testing laboratory has documented that building a working ISO 17025 system has required extensive operationalization of procedures and records, and the most difficult work has typically involved sustaining the governance routines as an embedded practice rather than as a one-time accreditation event (Zapata-García et al., 2007). Likewise, broader accreditation analyses in higher-education and institutional laboratories have described benefits such as strengthened quality concepts and improved comparability, while also documenting persistent challenges such as resource demands, cultural adoption, and maintenance of consistent QMS practices across changing workloads and staff turnover (Shi, 2021). Within that context, the present findings have reinforced an interpretive position that the measured compliance profile has represented a realistic "maturity gradient" in which the most visible and instrument-centered requirements have been rated highest, while the most decision-analytic and management-system-intensive requirements have lagged, even when overall compliance has been perceived as strong.

At the hypothesis level, the study's correlation and regression results have indicated that compliance maturity has been strongly associated with valve performance assurance ($r \approx .71$, $p < .001$) and that compliance dimensions collectively have explained a substantial share of performance assurance variance ($R^2 \approx .58$). This pattern has compared favorably with prior research that has linked structured management systems to improved operational outcomes when standards have been installed as replicable routines and used as part of daily work, rather than treated as symbolic compliance. In ISO 9000 research, performance benefits have been explained through the difference between "installation" and "usage," where real gains have emerged when standard requirements have been integrated into operational practice and used as catalysts for process control and improvement (Lei et al., 2022). The compliance–performance linkage observed here has been conceptually parallel, because ISO/IEC 17025 has similarly required not only documented processes but evidence of competence in routine execution, monitoring, and reporting. The study's strongest bivariate association has involved method validation/SOP adherence, and this has been coherent with the idea that method control has served as the "execution backbone" of any competence system: when method validation has been disciplined and SOP adherence has been consistent, laboratories have been more able to produce stable and comparable outputs, which has improved downstream confidence in valve conformity judgments. This interpretation has also been compatible with risk-management literature that has framed ISO/IEC 17025 as an international reference for trusted results and has argued that systematic risk-based thinking has supported achievement of management-system objectives by strengthening control over sources of invalidity (Santana & Loureiro, 2022). In other words, the present findings have not been isolated; they have fit a wider "standard-as-capability" narrative in which measurement validity and decision credibility have been amplified when method governance, evidence review, and improvement loops have been actively used rather than passively documented.

The regression outcomes have provided additional interpretive detail by showing that method validation/SOP adherence ($\beta \approx .31$) and competence/authorization ($\beta \approx .24$) have carried the greatest unique predictive weight for valve performance assurance, followed by calibration/traceability ($\beta \approx .19$), while audits/CAPA and uncertainty/decision rules have been smaller (and, for uncertainty, borderline) contributors in the multivariate model. This ordering has been important because it has suggested that, in the studied case configuration, "frontline execution controls" have been more influential than "back-end governance controls" in shaping how strongly performance assurance has

been perceived. Prior work on accreditation has supported this differential effect. For example, discussions of ISO/IEC 17025 implementation have emphasized that competence has been proven in the consistency of controlled operations—authorized personnel applying validated methods with controlled equipment—because this is where the majority of measurement variance and reporting errors have originated (Zapata-García et al., 2007). At the same time, resource-focused analyses of ISO/IEC 17025:2017 implementation have highlighted that laboratories have struggled to meet resource requirements, and such constraints have particularly impacted training continuity, system maintenance capacity, and the practical sustainment of competence over time (Krismastuti & Habibie, 2022). The present results have been consistent with that theme: competence and method governance have been perceived as high-value predictors because they have directly reduced variation in test execution and interpretation. In contrast, uncertainty/decision rules and audit/CAPA have been valuable but less salient predictors, which has plausibly reflected the operational reality that many organizations have implemented uncertainty documentation and audit schedules but have not uniformly translated them into consistent, risk-weighted decision rules that are applied identically across all valve types, acceptance thresholds, and service conditions. That pattern has aligned with research proposing structured risk management approaches within ISO/IEC 17025 systems, which has emphasized that risk-based thinking has required practical integration into daily decisions to yield full benefits (da Silva et al., 2021).

Figure 10: Integrated Multi-Layer Interpretation of How ISO/IEC 17025 Compliance for future study



When the findings have been connected back to valve performance evidence in oil and gas, they have also been compatible with technical literature showing that valve performance assurance has depended on repeatable, instrumented testing under critical conditions and on reliable interpretation of signatures that indicate leakage and degradation. For instance, experimental work on leakage identification in ball valves has demonstrated that pressure and torque signature analysis during cyclical tests has enabled leakage and failure-mode patterns to be quantified under critical operating

conditions, meaning that performance assurance has been achievable only if instrumentation and testing protocols have been stable and consistently applied (Teles et al., 2020). Similarly, control valve research has shown that stiction and nonlinearities have materially affected control-loop performance, and automated detection methods have required consistent data integrity and clear operational definitions of fault conditions, reinforcing the importance of method discipline and competence in producing decision-ready results (Choudhury et al., 2006). The present study's emphasis on method validation and competence has therefore mapped cleanly onto what "performance assurance" has meant in practice: if leakage detection, operability verification, or pressure integrity tests have been performed with method drift, inconsistent setups, or variable interpretation, then conformity decisions and reliability claims have weakened regardless of how strong the documentation looked on paper. The study has also supported a governance interpretation: ISO/IEC 17025 compliance has served as the mechanism that has connected technical testing outputs (e.g., leakage behavior, torque signatures, pressure containment evidence) to higher-level reliability confidence, particularly in contexts where valve failure consequences have been severe and where acceptance tests have been treated as central quality gates in the equipment lifecycle (Dora et al., 2017).

The practical implications have been most relevant for quality leaders and "assurance architects" who have designed compliance and reliability governance across global supply chains, including roles analogous to a CISO or enterprise architect in risk-heavy environments (e.g., Chief Integrity/Safety/Quality Officers, laboratory quality architects, and compliance program owners). The results have suggested that, to strengthen valve performance assurance at scale, governance has benefited most from prioritizing the "execution-critical" controls that have shown the largest predictive effects: method validation discipline, SOP adherence assurance, and competence authorization systems. This has meant that policy-level commitments (certification goals, audit schedules, documentation templates) have required translation into operational enforcement mechanisms such as: role-based authorization matrices for test execution and approval; competency revalidation schedules tied to method complexity; controlled templates that force uncertainty and decision-rule declaration for pass/fail calls; and instrument readiness gates that prevent testing when calibration or environmental controls have been out of tolerance (Jarvis et al., 2017). The comparatively weaker effects for uncertainty/decision rules and audit/CAPA have not implied that they have been unimportant; rather, they have implied that these controls have needed redesign so they have influenced day-to-day conformity decisions instead of remaining periodic or administrative activities. The risk-management literature has supported this approach by recommending practical, documented risk processes that have linked laboratory objectives to risk identification, mitigation actions, and evidence monitoring so that the QMS has actively protected result validity (Santana & Loureiro, 2022; da Silva et al., 2021). For procurement and vendor qualification architectures, the results have implied that supply-chain assurance can be strengthened by requiring not only ISO/IEC 17025 accreditation, but also explicit evidence of method validation practices and competence governance (e.g., method validation records, training authorization logs, uncertainty-decision rule declarations) as part of contract deliverables, because those mechanisms have been most strongly associated with performance assurance in the model.

The theoretical implications have supported refinement of the study's conceptual pipeline by clarifying how "compliance" has functioned as a capability bundle that has influenced valve performance assurance through measurable governance mechanisms. Prior scholarship has treated management standards as capabilities that have created advantage when they have been used as operational routines rather than as formal artifacts, and the present evidence has extended that capability logic into an ISO/IEC 17025 setting for mechanical testing and performance verification (Naveh & Marcus, 2005). The regression ordering has suggested that the compliance-performance relationship has not been uniform across mechanisms, which has supported a pipeline refinement in which method governance and competence controls have formed the "primary pathway," while audit/CAPA and uncertainty decision rules have formed a "secondary pathway" whose effect has depended on internalization and integration. In theoretical terms, the findings have been consistent with a two-layer model of competence systems: (1) an execution layer (competence, validated methods, controlled equipment)

that has directly reduced technical variance in results, and (2) a governance layer (audits, CAPA, risk thinking, decision-rule discipline) that has shaped long-run stability by reducing recurrence and strengthening interpretive consistency. Research on ISO/IEC 17025 risk management has provided formal support for that layered view by framing risk-based processes as mechanisms that ensure the management system achieves intended outcomes and that validity risks have been anticipated rather than merely corrected after failures occur (Santana & Loureiro, 2022). As a result, the study has contributed theoretically by specifying which parts of the competence system have been most tightly coupled to perceived performance assurance and by providing a statistically testable structure that can be extended in future work (e.g., testing mediation of “mechanical testing quality” between compliance and performance, or testing moderation by valve type and service severity).

Limitations have required careful interpretation of the findings, and revisiting them has clarified how the results should be used. The study has been cross-sectional and case-based, so causal inference has not been established; the observed relationships have represented statistical association and predictive modeling within the sampled context rather than proof of temporal causality. The study has also relied on Likert-scale perceptions, which have been appropriate for measuring governance maturity and assurance confidence but have not been direct measurements of physical leakage rates, failure frequencies, or field incident reductions. That limitation has been important because technical valve performance outcomes have often been influenced by factors beyond laboratory control, including valve design quality, installation practices, operating transients, and maintenance regimes; therefore, the VPA construct has represented performance assurance as experienced through testing evidence rather than full lifecycle performance. Measurement-system limitations have also existed because responses can be influenced by role-based visibility; for example, technicians can observe method and equipment discipline more directly than they can observe long-term CAPA effectiveness, which can contribute to the lower mean ratings and weaker regression effects for audit/CAPA and uncertainty. Implementation literature has emphasized that sustaining ISO/IEC 17025 has been resource-intensive, and the ability to maintain competence and evidence governance has depended on consistent resourcing and organizational integration, which has varied across institutions and can confound measured relationships (Grochau et al., 2018). These limitations have not invalidated the findings, but they have indicated that the results have been best interpreted as a robust “assurance maturity model” demonstration rather than as an absolute estimate of how much ISO/IEC 17025 compliance increases physical reliability in all oil and gas settings.

Future research has been positioned to extend the present results in ways that increase explanatory power and industrial generalizability while preserving measurement defensibility. First, longitudinal designs have been well-suited for testing whether improvements in method validation discipline, competence governance, and decision-rule consistency have preceded measurable improvements in rework reduction, dispute frequency, and (where available) field performance indicators such as leakage-related interventions. Second, multi-case studies across multiple laboratories and operators can test whether the regression ordering observed here has remained stable across valve families (ball, gate, globe, control valves), service conditions (sour service, erosive service, subsea), and organizational maturity levels. Third, integrating objective quality records—nonconformity logs, audit findings, proficiency testing outcomes, calibration out-of-tolerance events—can reduce reliance on perception-only measurement and can provide stronger evidence on how compliance mechanisms have operated as validity safeguards. Fourth, future modeling can incorporate mediation and moderation explicitly: for example, ISO/IEC 17025 compliance can be modeled as influencing “mechanical testing quality” (repeatability, traceability integrity, uncertainty completeness), which can then influence valve performance assurance and acceptance decisions; service severity and test complexity can be tested as moderators. Finally, technical integration studies can connect competence governance to performance analytics by examining how instrumented tests (pressure/torque signatures, leakage diagnostics) have required validated signal-processing methods and consistent decision thresholds, aligning operational diagnostics research with laboratory competence frameworks (Choudhury et al., 2006). This program of research can move the field from “compliance as a label” to “compliance as a measurable, optimizable assurance system” that has been explicitly linked to reliability evidence and performance

confidence in global oil and gas infrastructure.

CONCLUSION

The study has concluded that ISO/IEC 17025 compliance has functioned as a measurable and influential competence system within the mechanical testing environment of the oil and gas sector, and that higher compliance maturity has been associated with stronger valve performance assurance outcomes in the selected case-study context. By operationalizing ISO/IEC 17025 into key compliance dimensions—competence and authorization, calibration and metrological traceability, method validation and SOP adherence, internal audits and corrective actions, and uncertainty management with decision rules—the research has demonstrated that laboratory competence has not been a single uniform attribute but a structured bundle of governance mechanisms that have varied in maturity and in their predictive influence on performance assurance. Descriptive results have indicated that calibration/traceability and competence authorization have been rated most strongly, while internal audit/CAPA effectiveness and uncertainty-based decision consistency have shown comparatively lower maturity, which has reflected a practical gradient in how laboratories have internalized technical controls versus system-level learning and decision governance. The hypothesis testing outcomes have supported the core proposition that ISO/IEC 17025 compliance has been positively linked to valve performance assurance, with correlation results indicating significant positive relationships between compliance dimensions and outcome indicators, and regression modeling indicating that compliance mechanisms have collectively explained a substantial proportion of variance in valve performance assurance. Among the predictors, method validation and SOP adherence has emerged as the strongest determinant of performance assurance, followed by competence and authorization and calibration/traceability, which has highlighted that the most decisive factors for producing credible valve testing evidence have been those that directly stabilize how tests have been performed, controlled, and interpreted under repeatable conditions. Internal audits and corrective actions have contributed positively in the multivariate model, and uncertainty management and decision-rule consistency has shown a smaller contribution, which has suggested that improvement-oriented mechanisms and decision discipline have remained important but have exerted weaker influence unless they have been consistently integrated into everyday conformity judgments. Overall, the research has reinforced that valve performance assurance in global industrial infrastructure has depended not only on conducting mechanical tests but also on demonstrating the competence of the testing system that has produced the evidence, because acceptance decisions, compliance claims, and reliability confidence have relied on the validity, traceability, and repeatability of reported results. The study has further concluded that a quantitative, cross-sectional approach using Likert-scale measurement, reliability testing, correlation analysis, and regression modeling has provided an effective and defensible structure for evaluating compliance–performance relationships in a real operational setting, enabling compliance maturity and performance assurance to be expressed as interpretable numerical constructs that have supported hypothesis-based conclusions. At the same time, the study has remained bounded by the limits inherent to a case-based cross-sectional design and perception-based measurement, which has required that conclusions be interpreted as strong evidence of association and predictive structure within the observed context rather than universal causal proof. Taken together, the findings have established that ISO/IEC 17025 compliance maturity has been a central quality driver for mechanical testing credibility and valve performance assurance in the oil and gas sector, and that strengthening method governance, competence authorization, and traceability discipline has represented the most direct pathway for sustaining consistent and defensible conformity decisions in high-consequence industrial infrastructure.

RECOMMENDATIONS

Recommendations have been derived from the study's empirical pattern that ISO/IEC 17025 compliance maturity has been positively linked with valve performance assurance and that method validation/SOP adherence, competence authorization, and calibration/traceability discipline have carried the strongest predictive weight in the compliance–performance model. First, oil and gas testing laboratories and quality leadership have been recommended to strengthen method governance as a primary control, which has included maintaining method validation/verification files for each valve-related test scope (pressure integrity, seat leakage, torque/operability, cycling/endurance, and

material property checks), standardizing test setups through controlled work instructions, and enforcing procedural adherence through pre-test readiness checklists and peer verification before results have been approved. Second, laboratories have been recommended to formalize a competence and authorization architecture that has linked personnel training to specific test scopes, critical steps, and approval authority, supported by authorization matrices, periodic re-authorization based on competency re-evaluation, and documented supervision requirements for high-risk tests; this has ensured that execution consistency has been preserved across shifts and staffing changes. Third, laboratories have been recommended to enhance calibration and metrological traceability controls by establishing equipment “fitness-for-use” gates (preventing test initiation when calibration has been overdue or when environmental controls have been out of tolerance), documenting traceability chains for critical instruments used in leakage, pressure, and torque measurement, and applying systematic intermediate checks and drift monitoring for instruments that have experienced heavy use, transport, or harsh environments. Fourth, because internal audits and corrective actions have shown smaller predictive influence but have remained significant, organizations have been recommended to improve CAPA effectiveness by linking nonconformities to root-cause tools, setting measurable closure targets, verifying action effectiveness through follow-up audits, and prioritizing recurring nonconformities that have affected validity (e.g., inconsistent setups, incomplete records, procedural deviations) rather than focusing only on minor documentation formatting issues. Fifth, uncertainty and decision-rule consistency have been recommended to be strengthened through a decision-rule policy aligned with ISO/IEC 17025 reporting, where laboratories have documented how uncertainty has been handled in pass/fail judgments (e.g., guard-band rules), trained staff to apply the decision rule consistently, and included decision-rule statements in test reports so customers and auditors have interpreted conformity conclusions transparently. Sixth, oil and gas operators and manufacturers have been recommended to integrate these findings into supplier qualification and contract governance by requesting evidence packages that have gone beyond the accreditation certificate, including method validation summaries, calibration traceability evidence, key competency authorization logs, and sample reports showing uncertainty and decision-rule declarations for critical acceptance tests. Seventh, at the organizational governance level, a compliance “dashboard” approach has been recommended, where leading indicators (audit closure time, repeat nonconformities, proficiency check performance, calibration failures, report revisions, retest rates, and dispute frequency) have been tracked monthly and reviewed in management review meetings to ensure the competence system has been actively used to protect validity and improve performance assurance. Finally, continuous alignment between laboratory outputs and field reliability needs has been recommended by establishing structured feedback loops between testing teams and reliability/maintenance stakeholders, so that field failure or leakage findings have been translated into updated test scenarios, revised acceptance criteria, and enhanced method validation priorities, thereby ensuring that mechanical testing evidence has remained a robust and decision-ready foundation for valve performance assurance within global industrial infrastructure.

LIMITATIONS

The limitations of the study have been primarily associated with the research design, measurement approach, and the boundaries of the case-study setting within which ISO/IEC 17025 compliance and valve performance assurance have been examined. First, the study has been conducted using a quantitative, cross-sectional design, so the statistical relationships that have been identified between compliance dimensions and valve performance assurance have reflected associations at a single point in time rather than demonstrated causal effects across time; as a result, compliance maturity has been interpreted as a significant predictor within the modeled dataset, but temporal sequencing and cause-effect direction have not been empirically verified. Second, the study has relied on Likert five-point scale responses, which have been suitable for capturing perceived maturity of competence practices and perceived strength of performance assurance outcomes, but the approach has remained susceptible to perception-based biases such as social desirability, consistency motifs, and role-based optimism or pessimism. Respondents who have worked within accredited systems have sometimes evaluated compliance more favorably due to familiarity with audit expectations, while others have emphasized operational pain points (e.g., audit workload or documentation intensity), and such differences have

influenced construct means and relationships. Third, common method variance has been a potential constraint because independent and dependent constructs have been collected using the same survey instrument and response format; even though procedural steps such as confidentiality and neutral phrasing have supported measurement quality, shared measurement context has still had the capacity to inflate correlations. Fourth, although the sample has been purposively selected to include laboratory, QA/QC, inspection, and reliability stakeholders, the sample has not guaranteed equal representation across all job functions, and some roles have possessed partial visibility into specific compliance mechanisms; for example, technicians have typically observed equipment control and SOP adherence more directly than long-term CAPA effectiveness, and managers have had higher awareness of management review routines than of day-to-day setup variation, which has influenced item ratings and may have contributed to comparatively lower predictive strength for audit/CAPA and uncertainty decision-rule constructs. Fifth, the case-study boundary has limited generalizability because the results have reflected one organizational environment, one maturity level, and one governance culture, while oil and gas testing ecosystems have varied substantially by region, regulatory regime, valve family, service severity, and supplier qualification practice; therefore, the regression coefficients and rank-order of predictors have been treated as context-specific rather than universal estimates. Sixth, the study has operationalized valve performance as “performance assurance” rather than direct physical outcomes, so the dependent variable has captured confidence, consistency, and decision credibility rather than measured field failure rates, leakage volumes, or lifecycle reliability metrics; performance assurance has been a meaningful construct for compliance-oriented decision-making, but it has not fully represented all technical determinants of real-world valve failure behavior, which has also been influenced by design selection, installation quality, operating transients, and maintenance regimes beyond laboratory control. Seventh, the regression model has explained substantial variance in the outcome construct, but omitted-variable effects have remained possible because important contextual controls such as valve type distribution, pressure class mix, service chemistry, test throughput, and equipment age have not been modeled in detail, and these factors can affect both compliance execution and perceived assurance outcomes. Collectively, these limitations have required that findings be interpreted as a strong quantitative demonstration of compliance–assurance relationships within a defined case setting rather than as definitive causal evidence for all oil and gas laboratories and valve populations.

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