Quality Assurance as a Resilience Driver: An ISO 9001 Framework for Delivering Long-Life Roads, Bridges and Interchanges in NEOM.

Abstract

Roads, bridges and interchanges built for NEOM in north-west Saudi Arabia are expected to serve for many decades in a setting marked by seismic sources along the Gulf of Aqaba, episodic flash floods, intense solar exposure and coastal salinity. Quality management systems certified to ISO 9001 are a near-universal tender requirement, yet evidence suggests that certification often drifts away from what happens on site and rarely addresses performance after handover. This study asks how an ISO 9001 quality management system can be reoriented so that it acts as a driver of long-term resilience rather than as a compliance record. Following design-science research logic, it derives six requirements from thirty refereed studies published between 2020 and 2025 and from six disclosed documentary sources, builds a resilience-oriented framework around the clause structure of the standard, and evaluates the framework against those requirements with an explicit rating of evidence strength. The framework links climate-aware context analysis, durability-by-design review, digitally evidenced inspection and test plans, intelligent compaction and non-destructive testing, life-cycle performance evaluation and a corrective action loop that feeds service-life data back into design. The evaluation finds supportive evidence for digital traceability and corrective learning, mixed evidence for linking quality records to resilience metrics, and limited evidence for hazard-specific acceptance criteria in the NEOM setting. No primary or proprietary project data were analysed, and the framework is presented as a testable proposal for owners, contractors and certification bodies, including those preparing for the 2026 edition of the standard.

1. Introduction

Transport structures fail slowly before they fail suddenly. A bridge deck that was poorly cured, an embankment compacted unevenly, or an interchange drainage culvert sized without regard to extreme runoff may perform acceptably at handover and then lose capacity over years until a hazard event exposes the weakness. For a development of the scale announced for NEOM, which covers about 26,500 km² of the Tabuk region (Table 1, D5), the cost of such latent defects is

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multiplied by the length of the network and by the expectation that its assets will outlast several generations of users. Quality assurance therefore matters not only for compliance at completion but also for the ability of the network to absorb shocks and recover from them, the property that infrastructure scholarship describes as resilience (Liu et al., 2022; Poulin & Kane, 2021).

ISO 9001 is the most common vehicle through which construction organisations claim control over quality, and certification is frequently a precondition for bidding. Its value on site is contested. Interviews in three certified contractors showed that the system documented in the manual and the way projects were actually run had drifted apart, a pattern the authors describe as regulatory decoupling (Brooks et al., 2021). Survey work with quality managers found that compliance-oriented use, and documentation in particular, led executives to regard quality management as costly and of little strategic weight, whereas improvement-oriented use was valued more highly (Gremyr et al., 2021). Both studies imply that certification by itself is a weak guarantee that the durability and resilience of an asset will be managed deliberately.

Two developments make it timely to revisit the question. An amendment to ISO 9001:2015 issued in February 2024 required organisations to determine whether climate change is a relevant issue when analysing their context (Table 1, D1), and the sixth edition published in September 2026 now replaces the earlier text, with certified organisations given until September 2029 to transition (Table 1, D3–D4). At the same time, the delivery model for NEOM has shifted towards phased, commercially prioritised implementation (Table 1, D6), which places a premium on assets that are built right the first time and remain serviceable without costly intervention. These changes create an opening to treat the quality management system as an instrument for long-life performance rather than as a filing obligation.

The purpose of this paper is to design and evaluate an ISO 9001 framework that makes quality assurance an explicit driver of resilience for roads, bridges and interchanges in NEOM. Three objectives follow. The first is to derive, from recent evidence, the requirements that a quality system must meet if it is to influence durability and recovery performance over the service life of transport assets. The second is to construct a framework that maps those requirements onto the clause structure of the standard and onto practical controls. The third is to evaluate the framework against the requirements, distinguishing well-evidenced elements from those that remain conjectural. Three research questions guide the work: (RQ1) Which weaknesses in

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current ISO 9001 practice limit its contribution to long-term asset performance? (RQ2) Which controls, organised by clause, can connect quality evidence during construction to resilience outcomes in service? (RQ3) How strong is the published support for each element of the resulting framework?

The paper proceeds in seven further sections. Section 2 reviews research on quality systems in construction, durability and service life, infrastructure resilience, digital quality evidence and the NEOM hazard setting. Section 3 explains the design-science method and the disclosed documentary sources. The derived requirements appear in Section 4, Section 5 presents the framework, Section 6 reports the evaluation, Section 7 discusses implications and limits, and Section 8 concludes.

2. Background and Related Work

2.1 Quality management systems in construction

Empirical work on certified construction firms consistently finds a gap between holding a certificate and achieving mature quality practice. A comparison of certified Turkish contractors identified quality awareness education, training in quality tools, supplier quality data and internal customer satisfaction as the areas that most separated advanced firms from the rest, and proposed a staged route from certification towards total quality management (Budayan & Okudan, 2022). A survey of 326 personnel in Pakistani construction firms reported that a focus on operations, commitment from management and the involvement of employees were the dominant quality initiatives associated with project performance, with management commitment mediating the effect of involvement (Afzal et al., 2022). These findings point to leadership and competence, rather than documentation, as the levers that convert a certified system into better outcomes.

Studies of implementation gaps reinforce the point. A clause-by-clause assessment of a state-owned prefabricated building factory in Iraq estimated that the requirements for leadership, planning and performance evaluation were met to about two thirds, with the remainder only partially implemented or documented (Arslan et al., 2024). A Delphi study of Indonesian road projects found that problems with the availability of quality standards and documentation already appeared before construction began, and that the competence, commitment and cooperation of the project team were the critical constraints on quality control during pavement works (Willar et

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al., 2023). In Saudi Arabia, an analytic hierarchy model applied to building activities concluded that achieving quality was difficult across all operations examined (Alfalah et al., 2023), while a structural model built on 222 completed projects found that post-operational controls, audits, knowledge management and corrective scheduling were among the high-impact areas that underperformed (Alotaibi et al., 2025). Together, the studies describe systems that exist on paper but are weakly connected to the long-term fate of what is built.

Continuous improvement literature offers a partial remedy. A conceptual model of the plan-do-check-act cycle enabled by connected sensors, data analytics and automation argued that digital technologies can shorten the loop between detecting a deviation and correcting the process that produced it (Peças et al., 2021). The argument was developed for manufacturing, and its transfer to project-based construction, where each asset is unique and the operating phase is managed by a different organisation, cannot be assumed.

2.2 Durability and service life of transport assets

Durability is the bridge between construction quality and resilience, because the capacity of a structure to withstand a future hazard depends on how much of its original resistance has survived ageing. A review of service-life prediction under a changing climate argued that structures must be resilient not only at inception but throughout their life, and that climate loads should be built into codes and guides for designers (Lacasse et al., 2020). A recent review of concrete deterioration identified carbonation, reinforcement corrosion, cracking and freeze–thaw damage as the dominant pathologies of ageing bridges and proposed a multi-level strategy combining material design, strict construction quality control and planned maintenance (Ma et al., 2025). Strict control during construction is thus framed as one pillar of durability rather than as an end in itself.

Decisions taken early also shape service life. Work on pedestrian timber bridges proposed a three-step method that addresses shape, structural detailing and protection against degradation at the conceptual design stage, on the premise that durability is cheapest to secure before detailed design is fixed (Fiore et al., 2020). Although the material differs from the concrete and steel that dominate highway structures, the principle that durability must be reviewed as a design input transfers directly. A Swedish case study of bridge edge beams, whose reported average replacement age is only 45 years, showed through chloride diffusion and corrosion-cracking

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models that hybrid fibre-reinforced alternatives could extend service life while lowering life-cycle cost and emissions (Chen et al., 2023). The lesson for a quality system is that acceptance criteria tied only to strength at 28 days can miss the properties that govern decades of performance.

2.3 Resilience of infrastructure systems

Resilience research has grown rapidly but unevenly. A review of 222 articles from the decade to 2021 grouped the field into streams on assessment, improvement, conceptualisation, influencing factors and prediction, and called for more empirical work on interdependent systems (Liu et al., 2022). A critical review of 273 publications on resilience curves, which trace performance before, during and after a disruption, showed that the choice of performance measure and summary metric is often implicit and proposed a shared vocabulary to make assumptions visible (Poulin & Kane, 2021). For a quality system, the value of this vocabulary lies in giving managers a way to state which performance they intend to protect and how its loss and recovery would be measured.

Other contributions widen the frame. One essay argued that engineering conceptions of resilience must move beyond robustness to embrace adaptation, transformation and the capacity to cope with surprise, which demands agility in both physical assets and governance (Chester et al., 2021). A framework for transport assets combined greenhouse gas emissions, restoration time and cost into a single index and demonstrated it on a bridge to support recovery prioritisation across asset portfolios (Mitoulis et al., 2023). Practice-oriented work on adaptation proposed predetermined trigger points and flowcharts that prompt action when resilience weaknesses emerge, together with a chain-of-resilience concept for interdependent systems (Lewin et al., 2024). A review of ageing structures emphasised that deterioration and environmental aggressiveness must be explicitly modelled when the seismic resilience of bridges and road networks is assessed (Capacci et al., 2022). These strands converge on a simple message: resilience is a property of the asset over time, so quality controls that end at handover cover only part of the problem.

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2.4 Digital quality evidence in construction and operation

Digital tools now allow quality evidence to be captured in a form that survives the project. A workflow integrating building information models with geographic information systems, developed under design-science research and aligned with ISO 9001:2015, was tested on reinforced concrete walls and improved inspection traceability, the consistency of quality records and the identification of nonconformities (Araya-Santelices et al., 2025). For asphalt works, a new acceleration-based intelligent compaction index was reported to give more accurate evaluation than the commonly used compaction measurement value, with uniformity judged through a statistical spread criterion (Ma et al., 2022). Such methods move acceptance from spot checks to continuous coverage of the constructed surface.

Monitoring after construction is equally well served. A review of pavement condition monitoring systems for paved and unpaved roads described how automated sensing can reduce the time and cost of manual surveys (Shtayat et al., 2020), and an overview of ground-penetrating radar combined with other non-destructive tests concluded that integrated methods give a more complete picture of surface and subsurface defects caused by construction errors, ageing and environmental exposure (Elseicy et al., 2022). For bridges, a mixed-reality application linked to an information model supported remote inspection and maintenance decisions, letting engineers review defects against the model from the office (Nguyen et al., 2022), and a digital twin of a railway bridge demonstrated how the same model could support maintenance, resilience optimisation and the tracking of emissions and cost (Kaewunruen et al., 2022). A Norwegian highway case showed that online monitoring combined with physics-based and machine learning methods detected a rapidly developing critical damage early enough to halt its progression, though not early enough to avoid the incident entirely (Hagen & Andersen, 2024). Finally, a framework for life-cycle digitalisation of highway assets, based on 459 papers and 538 questionnaires, stressed unified classification, standard formats and linked data sources as preconditions for using such information across the life cycle (Huang et al., 2025).

2.5 The NEOM hazard and delivery setting

The physical setting of NEOM adds specific stresses. A seismicity study identified ten seismotectonic source zones around the project area and found the Gulf of Aqaba zone to be the most hazardous, with a maximum expected magnitude of 7.7, recommending formal hazard

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assessment to limit earthquake losses (Alzahrani et al., 2022). A morphometric analysis of drainage basins mapped flash flood susceptibility; it judged the overall likelihood of intense flooding to be very low but identified several large, elongated basins with long overland flow and low infiltration, which signals that hazard is uneven across the territory and must be assessed corridor by corridor (Bashir & Alsalman, 2023). A survey of 417 experts drawn from Saudi government bodies rated human resource, technology and contractual risks as very high for the project, above environmental and legal risks (Algumzi, 2022). The combination of uneven natural hazard and acute capability risk suggests that a quality system for NEOM must manage both the physical exposure of assets and the competence of the organisations that build them.

3. Method

3.1 Design-science approach

The study follows design-science research, which seeks to create and evaluate an artefact that solves a defined class of problems. The artefact here is a quality management framework, and the class of problems is the weak link between certified quality systems and the long-term performance of transport assets. Design-science logic proceeds through problem identification, the statement of objectives for a solution, design and development, demonstration and evaluation, which matches the structure of Sections 4 to 6. Because no access to live NEOM projects was available, demonstration is analytical rather than empirical, and evaluation rests on the strength of published evidence for each element.

3.2 Evidence base

The knowledge base comprises thirty refereed journal studies published from 2020 to 2025. Candidate records were identified in November 2026 through searches of an open scholarly index combined with checks against publisher registration metadata, using terms that paired quality management, ISO 9001 and quality control with durability, service life, resilience, asset management, pavement and bridge inspection, and the NEOM area. Two anchor studies, one on a digital quality workflow aligned with ISO 9001 (Araya-Santelices et al., 2025) and one comprehensive review of infrastructure resilience (Liu et al., 2022), were used to seed the search and to calibrate relevance. Studies were retained when they offered empirical, modelling or review evidence that could inform a requirement or a control, and each retained record was

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confirmed to carry a registered digital object identifier. Evidence was coded for the requirement or control it informed and for its type, whether case study, survey, modelling or review.

3.3 Documentary sources

Facts about the standard and about the NEOM programme are drawn from public documents rather than from the scholarly corpus, and these are disclosed in Table 1. They include the text of the climate amendment published by the standards body, the accompanying guidance on certification, the announcement of the 2026 edition and its transition timetable, and public reporting on the scale and delivery model of NEOM. These sources are used only to describe context; they are not counted among the reference list and do not carry analytical weight in the evaluation.

Table 1. Public documentary sources used for context (not counted among the reference list)

Code	Source and date	Type	What the source states
D1	ISO, ISO 9001:2015/Amd 1:2024, climate action changes (February 2024)	Standard amendment	Clause 4.1 adds that the organisation shall determine whether climate change is a relevant issue; clause 4.2 notes that interested parties can have climate-related requirements
D2	ISO and IAF joint communication on the climate amendment (March 2024)	Certification guidance	No formal transition programme was required for certified organisations to adopt the amendment
D3	ISO, ISO 9001:2026 standard page and launch notice (16 September 2026)	Standards body publication	Sixth edition replaces ISO 9001:2015 and its amendment; greater emphasis on leadership, quality culture and a clearer separation of risks and opportunities
D4	Global Accreditation Cooperation, transition requirements for ISO 9001:2026 (issued 4 September 2026)	Accreditation requirement	Three-year transition ending 30 September 2029; new and initial certifications only to the 2026 edition from 31 March 2028
D5	AGBI giga-projects tracker and press coverage of NEOM (accessed November 2026)	Business press	NEOM spans about 26,500 km² of north-west Saudi Arabia in the Tabuk region and was announced in 2017; The Line has been scaled back to an initial 2.4 km
D6	Press report of the Public Investment Fund annual report for 2025 (2026)	Press report of fund report	Ambitions for NEOM retained, with delivery moved to phased implementation and commercially driven prioritisation

3.4 Evaluation approach

Each framework element was evaluated against the six requirements stated in Section 4. Evidence for an element was rated supportive when two or more studies reported consistent empirical or modelled results relevant to the element, mixed when studies diverged or when support came from contexts that transfer only partially to highway infrastructure, and limited

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when support was conceptual or confined to a single study. The ratings describe the state of published knowledge rather than the likely performance of the element on any particular project. No interviews, site observations or proprietary quality records were used.

4. Requirements Derived from the Evidence

Six requirements emerge from the review and answer the first research question by naming the weaknesses that a resilience-oriented system must overcome. R1, coupling, requires that the documented system governs actual site practice, since decoupling was observed in every case examined by Brooks et al. (2021) and documentation-heavy use eroded management support (Gremyr et al., 2021). R2, durability-by-design, requires that service-life performance be reviewed as a design input and translated into acceptance criteria, following the evidence that early design choices and durability-related properties govern replacement age (Fiore et al., 2020; Chen et al., 2023).

R3, hazard awareness, requires that the context analysis identify the hazards to which each asset is exposed, including seismic sources, flash flood pathways and aggressive environments, and that these be traceable to design and inspection decisions (Alzahrani et al., 2022; Bashir & Alsalman, 2023; Lacasse et al., 2020). R4, evidential continuity, requires that quality evidence captured during construction remain usable during operation, which depends on linked data and consistent classification (Huang et al., 2025; Araya-Santelices et al., 2025). R5, performance linkage, requires that the system state which performance it protects and how loss and recovery would be measured (Poulin & Kane, 2021; Mitoulis et al., 2023). R6, organisational capability, requires that leadership commitment, competence and stakeholder cooperation be treated as controlled inputs, given the weight that surveys place on these factors (Afzal et al., 2022; Willar et al., 2023; Algumzi, 2022).

5. A Resilience-Oriented ISO 9001 Framework

5.1 Architecture

The framework, shown in Figure 1, retains the plan-do-check-act logic of the standard but stretches it across the full life of the asset. Planning covers context, leadership and risk; doing covers design review and operational control during construction; checking covers performance evaluation both at handover and in service; and acting covers nonconformity, corrective action

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and improvement. The decisive change from conventional practice is that the checking and acting stages continue after handover and that their outputs are routed back to the owner's design standards and the contractor's process controls. Clause references follow the 2015 numbering. The new edition adopts the harmonised structure shared by management system standards (Table 1, D3–D4), so the top-level clauses 4 to 10 are expected to persist, although detailed sub-clause numbers should be checked against the new text. The framework is organised in five control blocks, described below, and its clause-to-control logic underpins the evaluation in Table 2.

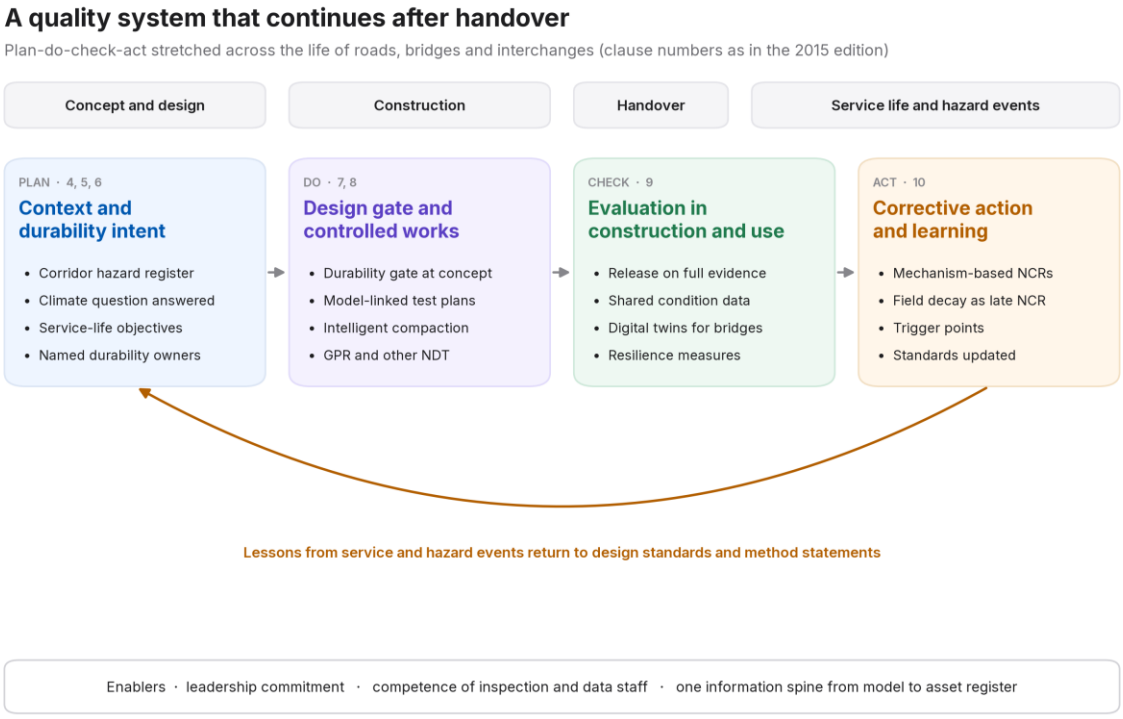


Figure 1. Resilience-oriented ISO 9001 framework spanning design, construction and service life

5.2 Context, climate and hazard register

Under clauses 4.1 and 4.2, the organisation determines internal and external issues and the requirements of interested parties. The framework asks that this analysis produce a hazard register for each corridor, recording seismic source zones, flash flood basins and drainage crossings, coastal salinity and thermal exposure, together with the asset classes they affect. The climate question introduced by the amendment (Table 1, D1) is answered not with a general

statement but with corridor-level entries that state design horizons and assumed climate loads, as recommended in work on service-life prediction (Lacasse et al., 2020). Because resilience thinking stresses adaptation and surprise, the register is reviewed after every significant event rather than treated as fixed (Chester et al., 2021). Interested parties include the future operator and emergency services, whose requirements for restoration time and detour capacity are recorded alongside those of the client.

5.3 Leadership, planning and durability-by-design

Clauses 5 and 6 address leadership, quality objectives and actions to address risks and opportunities. The framework sets at least one objective per asset class that is expressed in service-life terms, for example a target time to first major intervention, rather than only in completion terms. Design review under clause 8.3 includes a durability gate at concept stage, in which shape, detailing, drainage, protection and material choices are tested against the hazard register (Fiore et al., 2020; Ma et al., 2025). Where alternative designs exist, such as hybrid reinforcement for exposed edge elements, the gate compares life-cycle cost and environmental impact over the design horizon (Chen et al., 2023). Leadership commitment is made visible by assigning a named owner for each durability objective and by reporting progress to the project board, which responds to evidence that commitment mediates the effect of workforce involvement (Afzal et al., 2022).

5.4 Operational control and digital evidence

During construction, clauses 8.5 to 8.7 govern production, release and control of nonconforming outputs. Inspection and test plans are bound to elements of the information model so that every hold point, test result and nonconformity is located in space and linked to the design intent, as demonstrated for reinforced concrete elements (Araya-Santelices et al., 2025). For pavements, intelligent compaction provides continuous coverage of layer density and uniformity, and its records become part of the handover evidence (Ma et al., 2022). Ground-penetrating radar and complementary non-destructive tests are used at acceptance to confirm layer thickness and detect subsurface anomalies before they are buried by subsequent works (Elseicy et al., 2022).

Release of an element is conditioned on complete digital evidence, and incomplete records are treated as a nonconformity in their own right. This rule addresses the decoupling problem

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directly: when evidence is captured in the same environment that controls payment and handover, the documented system and the work on site are harder to separate (Brooks et al., 2021). Competence requirements under clause 7.2 extend to inspection staff and to those who interpret compaction and radar data, reflecting the finding that project team capability is the critical constraint on road quality control (Willar et al., 2023).

5.5 Performance evaluation through the life cycle

Clause 9 requires monitoring, measurement, analysis, internal audit and management review. The framework extends measurement beyond handover through a shared condition data model, so that the owner's monitoring of pavement condition and bridge behaviour uses the same classification and identifiers as construction records (Huang et al., 2025; Shtayat et al., 2020). For major bridges and interchange structures, digital twins combining sensor data with physics-based and data-driven models support early detection of damage (Hagen & Andersen, 2024; Kaewunruen et al., 2022). Performance is reported with explicit resilience measures, such as functionality loss and restoration time following an event, chosen according to the vocabulary set out by Poulin and Kane (2021) and the combined index proposed by Mitoulis et al. (2023).

Internal audit is redirected from document completeness to the coupling between system and site. Auditors sample completed elements, trace them back through the evidence chain and test whether recorded results match the as-built condition. Management review considers durability objectives, condition trends and hazard events alongside conventional metrics of cost and programme, which responds to the Saudi evidence that post-operational controls and audits are high-impact but underperforming areas (Alotaibi et al., 2025).

5.6 Nonconformity, corrective action and learning

Clause 10 completes the loop. Nonconformities found during construction are classified by the durability mechanism they threaten, such as cover, compaction, curing or drainage, so that corrective action addresses the process rather than the individual defect. Deterioration observed in service and damage after hazard events are treated as delayed nonconformities and traced back to construction records where possible. Lessons are then written into the owner's design standards and the contractors' method statements, using predetermined trigger points of the kind proposed for adaptation planning (Lewin et al., 2024). Digitally enabled improvement cycles can

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shorten the interval between detection and correction (Peças et al., 2021), but the framework requires that each cycle be closed by a named decision rather than by the mere existence of data.

6. Evidence-Based Evaluation

Table 2. Evaluation of framework elements against the derived requirements

Framework element	Clauses	Requirements addressed	Evidence rating	Main open question
Corridor hazard and climate register	4.1, 4.2, 6.1	R3, R5	Limited	Translating hazard levels into tolerances and inspection frequency
Service-life objectives and durability gate	5, 6.2, 8.3	R2, R3	Mixed	Transfer of durability evidence to desert highway structures
Model-linked inspection and test plans	8.5, 8.6	R1, R4	Supportive	Scaling from building elements to linear assets
Intelligent compaction and integrated NDT	8.5, 8.6	R2, R4	Supportive	Calibration for local materials and layers
Release conditional on complete evidence	8.6, 8.7	R1	Mixed	Whether digital capture reduces decoupling
Shared condition data model and digital twins	9.1	R4, R5	Supportive	Cost and ownership of data after handover
Resilience measures in management review	9.3	R5	Mixed	Linking construction quality to restoration time
Coupling-focused internal audit	9.2	R1, R6	Mixed	Auditor competence and access to site
Mechanism-based corrective action and trigger points	10.2, 10.3	R2, R6	Supportive	Closing the loop across separate organisations
Competence controls for inspection and data roles	7.2	R6	Supportive	Supply of qualified staff at scale

Table 2 summarises the evaluation, and Figure 2 illustrates how the framework intends to change the resilience curve of an asset; the curve is schematic and does not represent measured data. Elements addressing evidential continuity and corrective learning receive supportive ratings. Several studies report that digital workflows improve traceability and the identification of nonconformities, that continuous compaction measurement improves acceptance accuracy, and that integrated non-destructive testing and online monitoring detect defects that manual methods miss (Araya-Santelices et al., 2025; Ma et al., 2022; Elseicy et al., 2022; Hagen & Andersen, 2024). The requirement for organisational capability is also strongly supported, since surveys in several countries converge on leadership, competence and cooperation as determinants of quality outcomes (Afzal et al., 2022; Budayan & Okudan, 2022; Willar et al., 2023).

Durability-by-design and coupling receive mixed ratings. The principle that early design and durability-related properties govern service life is well established, but the supporting studies

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concern timber footbridges and Nordic edge beams rather than desert highway structures (Fiore et al., 2020; Chen et al., 2023). Evidence that digital evidence capture reduces decoupling is inferential: decoupling has been documented (Brooks et al., 2021), and digital traceability has been shown to improve record consistency (Araya-Santelices et al., 2025), but no study has tested whether the latter cures the former. Linking quality records to resilience metrics is likewise rated mixed, because resilience curves and combined indices are mature at the asset level (Poulin & Kane, 2021; Mitoulis et al., 2023) while their connection to construction quality data has not been demonstrated.

Hazard-specific acceptance criteria for NEOM receive a limited rating. Hazard studies characterise seismic sources and drainage basins (Alzahrani et al., 2022; Bashir & Alsalman, 2023), but they do not translate hazard levels into construction tolerances or inspection frequencies, and the flood mapping itself reports a low overall likelihood of intense flooding that coexists with locally susceptible basins. Translating these findings into acceptance criteria will require project-specific engineering that the published literature does not yet supply. Overall, the evaluation answers the third research question: the framework rests on firm ground where it digitises and connects quality evidence, on partial ground where it links that evidence to resilience, and on thin ground where it relies on hazard-specific criteria.

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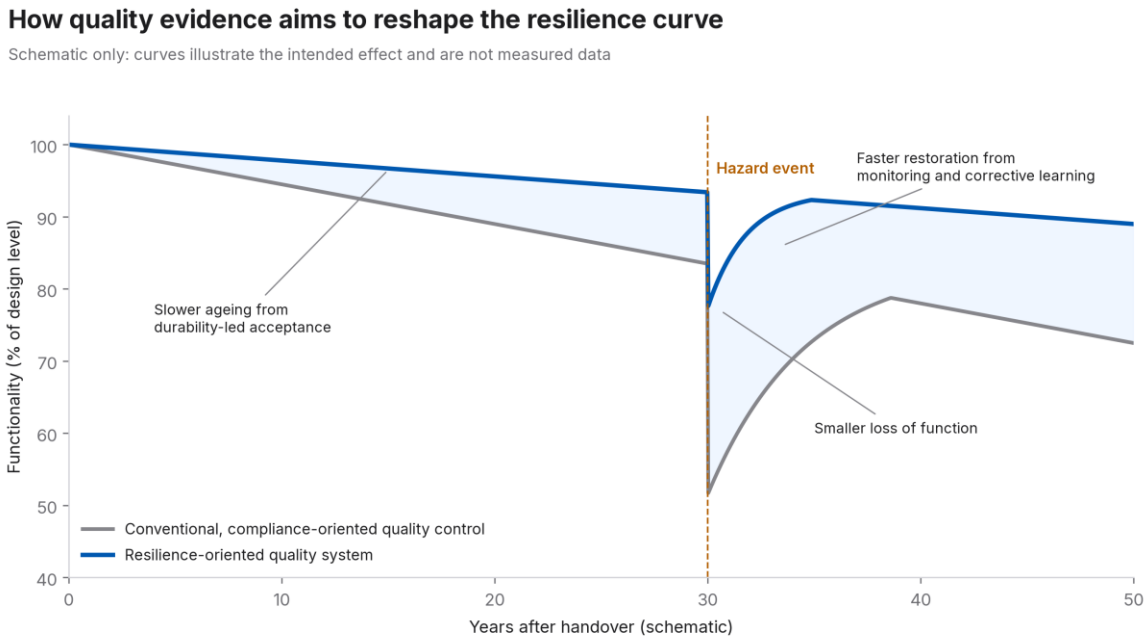


Figure 2. Schematic resilience curves for an asset delivered under conventional and resilience-oriented quality control (illustrative, not measured data)

7. Discussion

The framework reframes the quality system as the custodian of an asset's capacity to resist and recover, not only of its conformity on the day of handover. This reframing has three practical consequences. For owners, it implies that quality requirements in contracts should include service-life objectives, evidence formats and access to condition data, so that contractors' systems and the owner's asset management share one information spine (Huang et al., 2025). For contractors, it implies that inspection effort should be concentrated on the properties that govern durability, such as cover, compaction and curing, and that complete digital evidence should be a condition of payment. For certification bodies, it suggests that audits should test coupling between the documented system and the work on site rather than the completeness of procedures, which addresses the decoupling and compliance-oriented use documented in the literature (Brooks et al., 2021; Gremyr et al., 2021).

The timing of standard revision makes these consequences more immediate. Organisations certified to the 2015 edition must transition to the 2026 edition by 30 September 2029, and new certifications will be issued only against the new edition from 31 March 2028 (Table 1, D4). The

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new edition is described by its publisher as placing greater emphasis on leadership, quality culture and a clearer separation of risks and opportunities (Table 1, D3). These emphases align with the capability and planning elements of the framework, and the transition period offers a natural moment for NEOM contractors to rebuild their systems around long-life performance rather than to update documents mechanically. Because the present analysis was prepared from the publisher's summary rather than from the full revised text, detailed clause mapping to the 2026 edition should be confirmed before adoption.

The NEOM setting both strengthens and complicates the case. Seismic sources and uneven flood exposure argue for hazard registers and resilience metrics, while the strong rating that experts give to human resource and technology risks argues for competence controls (Alzahrani et al., 2022; Algumzi, 2022). Public reporting indicates that the programme has moved to phased, commercially prioritised delivery and that some elements have been scaled back (Table 1, D5–D6). A phased approach, if anything, raises the value of a learning loop: lessons from the first corridors and interchanges can be written into the standards for later phases, which is the mechanism the corrective action block is designed to support (Lewin et al., 2024).

Several limitations qualify the contribution. The evaluation is analytical and depends on published evidence, much of which comes from other countries, building rather than highway projects, or single case studies. The corpus is limited to thirty studies and may omit relevant work in other languages or in practitioner literature. No primary data were collected, no proprietary quality records were examined and the framework has not been piloted on a NEOM project. The evidence ratings are judgements by a single analyst and should be read as transparent but provisional. Finally, the framework does not replace structural, geotechnical or hydraulic design, which remain the primary defences against hazard loads.

Future research could test the framework through pilot application on one corridor, comparing the completeness of evidence, the rate of repeat nonconformities and early condition trends against conventional practice. Longitudinal studies linking construction records to condition data and post-event behaviour would supply the missing evidence for performance linkage.

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8. Conclusion

This paper has argued that an ISO 9001 quality management system can serve as a resilience driver for long-life transport assets, provided it is redesigned to look beyond handover. Drawing on thirty recent studies, it identified six requirements, from coupling the system to site practice through to organisational capability, and constructed a framework that maps them onto the standard's clauses. The framework combines corridor-level hazard registers, durability gates in design review, digitally evidenced inspection and testing, life-cycle performance evaluation with explicit resilience measures, and a corrective action loop that returns service-life lessons to design and construction standards.

The evaluation shows that the framework is strongly supported where it digitises and connects evidence, partially supported where it links quality to resilience, and weakly supported where it depends on hazard-specific criteria for NEOM. These ratings indicate where owners and contractors can act with confidence and where pilot studies are needed. As certified organisations transition to the 2026 edition of the standard, NEOM offers an opportunity to show that quality assurance can protect not just conformity at completion but the capacity of roads, bridges and interchanges to keep serving through the hazards of the coming decades.

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