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RESEARCH ARTICLE

DIGITAL TRANSFORMATION OF ELECTRICAL AND INSTRUMENTATION INSPECTION, TESTING AND COMMISSIONING IN SAUDI OIL AND GAS PROJECTS

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Abstract

Electrical and instrumentation inspection, testing, and commissioning (E & IITC) determine whether installed equipment, protection functions, and control interfaces are sufficiently trustworthy for safe oil and gas start-up. Yet digital transformation research focuses mainly on asset production rather than the temporary, evidence-intensive transition from construction to operations. This integrative review analyzes how digital quality records, connected test instruments, asset information models,analytics, and cybersecurity controls can improve that transition in Saudi projects. A transparently scoped literature synthesis links petroleum digitalization with research on construction assurance, sensor calibration, digital twins, and industrial control security. The evidence supports a conditional proposition:value arises when traceable test results, engineering identifiers, calibrated measurements and authorized acceptance decisions remain connected across contractors and lifecycle systems. Automation alone cannot establish electrical safety, instrument accuracy, or functional acceptance. The paper develops a stage-gated assurance architecture, distinguishes mature uses from speculative ones, identifies testable research gaps, and proposes implementation and governance priorities. The principal contribution is an E&I-specific, evidence-centered account of digital commissioning that avoids attributing unverified productivity gains to Saudi projects.

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Introduction:-

Commissioning is the process of establishing that a complex petroleum installation is fit for operation through inspection, testing, correction, verification, and formal handover. The electrical and instrumentation work includes cables, switchgear, earthing, analyser systems, field instruments, control loops, programmable systems and interfaces to safety systems. A test that has passed is only of any value if the relevant parties can establish what was tested, by what method and with what calibrated instrument, against what acceptance criterion and in what configuration. Keeping these relationships is very difficult through construction handover and subsequent modification if you rely on paper dossiers and disparate spreadsheets.Saudi oil and gas projects involve several engineering, procurement, construction, commissioning and operating organisations all working together. The practical pressures of multicontractor delivery, large equipment inventories, the harsh outdoor environment, and the

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presence of hazardous areas create a need for consistent records. Many Gulf petroleum operations are interested in digitalisation, as evidenced by the number of published reviews. The vast amount of publications and the number of operational use cases should not be taken as evidence of independently demonstrated E&I commissioning outcomes (Al-Hajri et al., 2024; Maroufkhani et al., 2022). The opportunity is therefore much more clearer than an aspiration to digitise everything. The opportunity is to make the safety-critical acceptance evidence accessible, understandable and durable.

Digital quality inspection systems show that structured, timely documentation can lead to increasingly robust site decisions. That said, evidence from general construction does not necessarily translate to performance in explosive atmospheres or energised electrical systems (Hussamadin et al., 2023). The same applies to intelligent asset systems, which can link engineering information to future maintenance. Their value depends on the owner's information needs and the completeness of the data (Thabet et al., 2022). This review brings the two bodies of literature together while recognising differences in operating context, evaluation methods, and evidence strength.

Aim of the Study:-
The study is to develop a rigorous, evidence-based account of how digital technologies can be used to improve the traceability, reliability and governance of E&I inspection, testing and commissioning on Saudi oil and gas capital projects and to establish the conditions under which any such improvements are genuinely achievable from both a technical and an organisational perspective.

Research Objectives:-
The objectives are: (O1) to map digital approaches to the various E&I assurance tasks; (O2) to assess the extent to which measurement integrity and asset identity underpin the validity of electronic test evidence; (O3) to compare the possible benefits against the associated implementation, safety and cyber security risks; (O4) to develop an integrated handover and acceptance framework for use in multi-contractor projects; and (O5) to establish measurable research priorities for the Saudi commissioning environment.

Research Questions:-
RQ1 is about which technologies are most defensibly applicable to particular E&I inspection and commissioning activities. RQ2 is about what information and assurance controls are required to make electronic evidence auditable. RQ3 asks how technical, organisational, and cyber security barriers affect the expected benefits. RQ4 asks how project teams can link commissioning records to operational asset systems without transferring unresolved defects or untrusted data. RQ5 asks what comparative evidence is required to validate the outcomes of the Saudi projects.

Review Methodology:-

An integrative, structured literature review was chosen because the question spans construction engineering, electrical metrology, oil & gas operations, digital information management,t and cyber-physical systems. A very narrow meta-analysis would be inappropriate, as it would aggregate quite disparate outcomes. An unstructured narrative would likely hide the selection rationale. The unit of analysis was a mechanism or an empirical finding that could in some way inform E&I assurance. There was no claim that all of the papers reviewed actually looked at Saudi commissioning.

Search concepts were "oil and gas" OR petroleum OR refinery combined with digital transformation, inspection, testing, commissioning or turnover. These were augmented with combinations of digital quality control, instrument calibration, asset handover, building information modelling, industrial internet of things, digital twin, predictive maintenance and operational technology security. Scopus, Web of Science, Engineering Village and IEEE Xplore were the primary routes for scholarly discovery, with Crossref and publisher DOI pages used for bibliographic checking and citation chasing. The reference set is the result of targeted source identification and DOI checking rather than a fully executed, reproducible database export. Fictitious initial hits, exclusions and PRISMA flow counts are therefore not reported.

Eligibility was for peer-reviewed papers from 2020 to 2025 reporting on empirical applications, rigorous reviews or relevant technical frameworks. Earlier work was acceptable only if it was essential. The evidence base excluded marketing material, product brochures, unsubstantiated claims (undated or otherwise), non-peer-reviewed industry case studies, and papers that couldn't be verified as actual papers. We included transferable studies from manufacturing and the built environment if they concerned inspection evidence, lifecycle information, or industrial

risk. We assessed Saudi relevance based on relevance to the project's workflow, rather than assuming a study from a different geographical location was necessarily valid.

Appraisal focused on publication provenance, methodological transparency, directness to E&I commissioning, reproducibility of measurements, and disclosure of operational constraints. Reviews were not considered to be independent replications of the underlying experiments. The synthesis utilised an evidence-to-workflow matrix, contrastive thematic coding and causal reasoning to establish the required controls. PRISMA 2020 informed the principles of open reporting, but this is an integrative review rather than a fully PRISMA-compliant systematic review (Page et al., 2021). The lack of a saved database-by-database screening log, the absence of independent dual review, and the lack of formal risk-of-bias scoring all limit how far we can claim comprehensiveness.

During the synthesis, we categorised the evidence as direct commissioning evidence, transferable engineering practice or conceptual guidance. Direct evidence would have required documented E&I field outcomes, and the set contained very little. Most of the technical content came from transferable practice, and the architecture and discussion drew on one conceptual source. Such structure matters because it prevents the review from taking a general digital twin case study and treating it as evidence of actual electrical commissioning performance. It also explains why qualitative convergence is the more defensible outcome here than any pooled effects or sector-wide numerical forecasts.

Thematic Literature Review and Critical Analysis:-

Digital records and inspection execution. Site inspections generate observations, photos, checklist decisions, non-conformance reports and sign-offs. Structured mobile forms can enforce mandatory fields, link findings to tagged assets, and prevent completion without approval. Hussamadin et al. (2023) highlight the value of construction quality documentation as process information, but interface usability and faster form completion do not necessarily reduce electrical defects. The key question is whether the evidence is capable of being independently rechecked, not whether it's just searchable.

Digital inspection reviews in modular construction focus on image capture, sensing, and integrating quality across the process (Li et al., 2023). The relevance to Saudi E&I work is somewhat limited: visual confirmation can be valuable for labelling, cable routing, gland installation, and mounting condition. However, insulation resistance, protective relay performance, and intrinsically safe circuit integrity will require specialist instruments and a qualified person to interpret the results. Remote imagery will not in any case replace functional demonstration where failure has a safety implication. Data capture procedures must also respect restricted-area photography policies and cybersecurity boundaries.

Test instruments, calibration and provenance. Instrument calibration is a metrological activity, not a database transaction. Multi-criteria approaches can improve the evaluation of digital measuring devices under given uncertainty assumptions (Klebba et al., 2023). Online monitoring of calibration status also shows that sensor dependability is not static and should inform maintenance decisions (Martins et al., 2023). Neither of these papers in any way supports the proposition that you can accept an E&I test simply because a tablet has given you a reading. A reliable workflow will tie together the test value, unit, timestamp, ambient conditions, instrument serial number, calibration status, technician authorisation and acceptance limit in a single, controlled record.

Another distinction is between raw readings and derived judgements. Raw data should be available where the equipment allows. The automatic pass/fail logic must be versioned and linked to the approved procedure. Measurement uncertainty is of course important near the limits and will be of particular relevance when instrument accuracy, lead resistance or environment are all factors in the final judgement. A device with an expired calibration cannot become compliant simply by virtue of a digital sync. On the other hand, properly governed automatic acquisition can reduce transcription errors while keeping witnessing and engineering judgement intact.

Asset information, digital twins and turnover. Reviews of digital twins distinguish between a synchronised cyber-physical model and a static model, highlighting inconsistent definitions and the cost of integration (Sharma et al., 2022; Atalay et al., 2022). The distinction is important in that a 3D plant model with PDFs attached is not in itself a validated operational twin. Onaji et al. (2022) focus on architectural integration, while Fu et al. (2022) concentrate on integrating design, production, and maintenance information. For commissioning, the defensible near-term application is a controlled asset record containing configuration, outstanding defects, verified tests and availability status.

The AECF literature is full of references to ongoing interoperability problems (Hosamo et al., 2022). Attencia and Mattos (2022) also point out that asset management adoption depends as much on the organisation's context and decision processes as on technical capabilities. Automated export from the design model to the asset system will, to some extent, eliminate the necessity for manual re-entry. Still, without a commissioning validation step, errors in the source model will propagate downstream (Thabet et al., 2022). Smartphone-based asset reconstruction is a different capture mode with its own practical compromises between effort and geometrical accuracy (Selvakumaran and Hall, 2022). In the oil and gas sector, the digital handover must reconcile physical nameplates, cable schedules, instrument indexes, cause-and-effect matrices, and control system tag databases before the equipment register can be deemed authoritative.

Analytics, reliability and safety. The predictive maintenance literature often discusses how connected sensors and models can predict degradation. It also includes caveats about data quality, domain selection, and validation (Zonta et al., 2020; Mallioris et al., 2024). Maintenance transformation is therefore inextricably linked to but distinct from commissioning acceptance (Silvestri et al., 2020). New equipment has no operating history, and models developed on existing equipment cannot simply certify first energisation or first process introduction. Analytics is far more defensible in terms of detecting duplicate tags, implausible values, recurring punch categories and inconsistent completion sequences.

He and Bai (2021) position digital twins as part of the wider intelligent manufacturing evolution, while Nazari and Musilek (2023) provide a broad synthesis of the applications in the energy sector. The manufacturing evidence is geared toward a cross-lifecycle approach, but it doesn't eliminate the need for physically witnessed safety system performance tests. Digital tools are able to, of course, highlight incomplete loops and defect clusters, but proof of safe function still rests on field testing and the quality of the witness. The AR work suggests benefits in contextualising maintenance instructions, but visual overlays can be a distraction and may show an out-of-date configuration (Gattullo et al., 2022).

Petroleum transferability and the Saudi setting. A review of petroleum digitalisation identifies analytical, cloud, and automation opportunities across exploration and production (Al-Rbeawi, 2023). D'Almeida et al. (2022) look at the application of AI in drilling and production, not E&I turnover. Haouel and Nemeslaki (2024) highlight strategic, capability, and ecosystem barriers to digitalisation in petroleum. Taken together, these provide a credible enabling environment but do nothing to establish quantified benefits in terms of Saudi commissioning schedule, defect escape rates or safety performance. Transferability will depend heavily on the contractual structure, system scope, owner requirements, and regulator expectations.

Operational technology and cyber-physical assurance:-
The potential for exposure increases significantly during startup configuration because of connected test benches and remotely accessible control systems. Industrial internet security surveys have highlighted heterogeneous attack vectors and implementation requirements (Abosata et al., 2021; Agrawal and Kumar, 2022). Process control cybersecurity work has clearly shown that traditional office information security assumptions are insufficient to capture the implications of a physical process (Parker et al., 2023). A commissioning platform should never be granted unrestricted write access to a live controller simply because it's convenient to integrate the data.

Intelligent intrusion detection has potential but can be compromised by poor-quality training data and by changing network conditions (Nuaimi et al., 2023). Threat modelling for industrial control systems highlights the importance of assessing safety and cybersecurity in tandem (Khalil et al., 2024). Organisational awareness is an additional control, not a replacement for network segmentation and access control (Lazoi et al., 2022). Practical controls include signed software versions, controlled interfaces, access that expires after a set period, immutable audit trails, and formal change management when a tested configuration is changed.

The studies reviewed vary considerably in what they consider to be a successful digital intervention. The petroleum papers focus on organisational uptake and operational improvement, the construction papers on documentation completeness, and the industrial security papers on exposure and resilience. You can't really rank those different outcomes on a single maturity scale. For commissioning, the only useful commonality is evidence of decision quality. The authorised reviewer must be able to walk through the chain from requirement to observation, evaluation, exception and final acceptance. A system can be very technically sophisticated and yet fail that criterion entirely if its asset taxonomy is all over the place.

Commissioning brings its own set of temporal problems. Evidence is generated while the underlying plant is in flux: cables are being terminated, devices are being replaced, logic is being changed, and packages are crossing disciplinary lines. An operating digital twin typically runs from a stable configuration against which telemetry can be interpreted. The commissioning information model cannot make that assumption. It must describe a provisional state, a state of partial installation and successive retesting, without implying that previously accepted evidence remains valid after a change. The fundamental data relationship is therefore between a configuration change and the consequent obligation to re-validate.

The same issue arises with what appear to be straightforward completion percentages. A loop can be mechanically complete, electrically continuous and individually calibrated and yet still fail to do its intended sequence because the upstream permissive hasn't been checked. Merging those states leads to overly optimistic 'ready' indicators. A useful digital taxonomy would separate inspection completion, isolated equipment testing, integrated functional verification, and operational transfer. That would let the team focus on the significant interfaces rather than chasing closure of low-value checklist items.

Discussion: An Evidence-Centered Commissioning Model:-

Cross-disciplinary evidence points to digital maturity being measured by the integrity of the commissioning assurance chain rather than the number of applications. A fully electronic checklist is still going to fail if it's linked to the wrong loop, it's based on the wrong drawing, or it's accepting a reading from unqualified equipment. On the flip side, a fairly simple system which links asset identity, instrument provenance and approval authority can deliver a huge amount of governance value without any need for sophisticated simulation. That, in itself, underpins the broader assertions that digitalisation generally improves safety or productivity.

Figure 1 shows the proposed workflow from design baselines to operational handover. The gates are interpretive rather than regulatory. The engineering and quality teams define the approved inspection and test plan. The qualified technicians produce the evidence. An independent review team determine whether the acceptance criteria have been met. Operations then accept the configuration-linked packages. Exceptions will, of course, branch back to rework and retest. The configuration identifier must link each loop or equipment tag to the exact drawing revision and device setting so that a result from an earlier pass cannot be reused after the material has been changed.

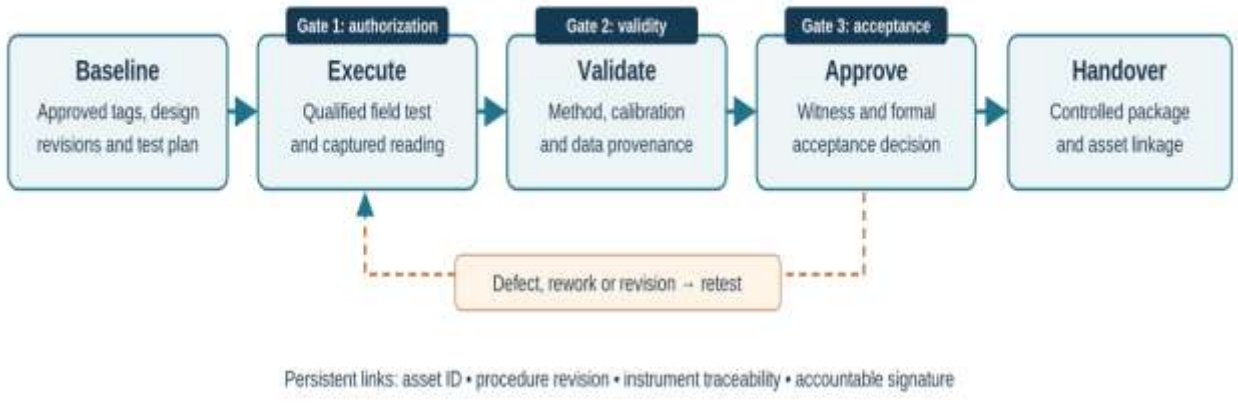


Figure 1. Proposed evidence-centered E&I commissioning workflow and decision gates (author synthesis; conceptual, not field-tested).

Table 1 contrasts interventions by evidence type, likely failure mode and minimum governance requirement. The table deliberately excludes unsupported estimates of hours saved. Its purpose is to help decision makers distinguish tools that digitize documentation from those that affect measurement validity or system behavior. Interoperability should be tested through a small number of representative assets before enterprise rollout, including assets with shared I/O, vendor package boundaries, safety-critical instrumentation and late design changes.

Table 1. Technology–evidence–risk mapping for E&I commissioning (author synthesis).

Digital intervention	Primary evidence enabled	Principal failure mode	Minimum safeguard
Mobile inspection workflow	Tagged observation and signed checklist	Wrong asset or obsolete procedure	Identifier and revision validation
Connected test instrument	Timestamped reading and metadata	Uncalibrated device or incorrect limits	Traceable calibration and approved criteria
Asset information integration	Linked test and engineering history	Incorrect model-to-field mapping	Physical tag reconciliation
Analytics and exception flags	Prioritized conflicts and anomalous data	False confidence in automated decisions	Human review and rule versioning
Remote technical collaboration	Witness notes and rapid clarification	Uncontrolled access to operational technology	Network separation and least privilege

Figure 2 develops a layered assurance model. Foundational technical controls enable records, but decision authorization sits above them; independent verification cuts across all levels. The model rejects technological determinism: attaching sensors to a poorly governed work process may increase data volume and ambiguity. Likewise, the existence of an impressive dashboard is not proof that a subsystem can be safely energized. A useful key performance indicator is the percentage of accepted records passing an independent traceability audit, not the number of checklists uploaded.



Figure 2. Layered assurance conditions for trustworthy digital commissioning (author conceptual model).

A sensible measurement framework would separate out process efficiency from quality and risk. Potential metrics would be time from inspection request to verified approval, first pass test acceptance, time to late defect discovery, % of records with valid calibration link and handover retrieval time. Safety outcomes will require a sufficiently long period of observation and control in order to adequately assess project risk exposure and incident counts on their own are too sparse to be easily attributable. Any comparative studies would need to take into account equipment complexity, contractor experience, construction readiness and change volume. Without those controls the correlation between the software roll out and project success is going to be very weak causal evidence.

Take a pressure transmitter loop which has passed its field calibration but whose control room range is different from the latest approved data sheet. The digital dashboard might show two activities as complete, whilst the integrated system is still not ready. The evidence centred model would treat the agreement between installation, calibration, control configuration and the final loop function as the object of acceptance. The same principle applies to relay protection where recording a secondary injection result is of no value if the installed settings are not the same as those approved for the live network. These are all purely analytical examples, not actual incidents or measured results from a Saudi site.

Evidence retention is a lifecycle issue. The contractor will typically demobilise after turnover, the operator however will be looking at the records during the course of troubleshooting and subsequent modifications. Records therefore have to have defined custodianship, defined export formats and robust identifiers that will survive platform change. The principle is straightforward really: commissioning evidence is part of the asset lifecycle not just the lifecycle of the application that produced it.

Quality assurance also requires visible disagreement. If one contractor marks a loop as complete and an independent witness records a divergence then both records (with timestamps and resolution history) need to be retained on the platform. You don't simply replace the original record with a clean status as that erases the rationale for acceptance. A preserved audit trail turns disagreement into reviewable evidence.

Data stewardship should be about distinguishing the authoritative document from the convenient copy. The engineering team might have the approved data sheets, the commissioning team the working extracts and the vendor the instrument files. The system should be able to say which source controls each attribute, when the sync occurred and who can approve a discrepancy. Without those assignments you end up with centralisation which in effect just hides the fragmentation.

Human competence remains fundamental. Software validation can prevent impossible dates or absent serial numbers; it cannot establish that a technician connected leads correctly or interpreted a hazardous-area requirement appropriately. Competency assessment, supervised practice, safe isolation and independent witnessing therefore remain complementary controls. Digitalization should make these responsibilities clearer rather than obscure them behind automated status indicators.

The order of deployment has an impact on risk. Digitising static evidence and defect registers is generally going to be less of an integration risk than live interaction with the operational controllers. That means that project sponsors can go ahead and prioritise the low risk data integrity work before they authorise any software that will be reading the process networks. That sequencing allows you to learn about user behaviour, identifier mismatches and exception rates without actually putting the production controls at risk.

Another source of uncertainty is the variety of contractual acceptance arrangements. Some projects will require multiple signatures from the contractor, consultant and owner at various hold points; others will have a different approach. The proposed model is deliberately role based so that organisations can set their own responsible parties without having to impose a single universal approval hierarchy. All authorities must be derived from the relevant project quality plan.

The theoretical enthusiasm for digital twins also serves to blur the line between a model and an evidence repository. A model is a representation of physical behaviour (a prediction); a repository is simply a record of what people were allowed to see. They can be linked, of course, but they have different validation requirements. An engineering simulation can be of value in terms of understanding a response but it will not in any way replace the measured response during an approved test. It is absolutely vital to maintain the distinction between a prediction and an observed piece of evidence in the case of protective interlocks and emergency shutdown functions.

Acceptance logic should be able to accommodate uncertainty and conditionality rather than forcing a pass/fail status at every stage. If a test is blocked because a vendor package is not available then the record should state that it is blocked, state the reason for the block and maintain accountability. If a result is very close to an allowable limit a competent reviewer may require confirmation or an uncertainty assessment. Software workflows which simply collapse these into pass and fail run the risk of hiding the reasons why the responsible engineers were in any doubt as to whether or not they should have accepted the result.

There's also a line to be drawn between internal efficiency and external trust. Project managers will care about faster approvals, but owners and the people who will be maintaining the system in the future will care about the level of trust they can place in those approvals. An intervention that reduces cycle time but at the same time increases the amount of missing calibration information is not a success in all respects. The evaluation therefore needs to use a pair of metrics, one that measures throughput and one that measures the validity of the evidence. A balanced scorecard will of course work against the organisational tendency to equate an electronic task as closed with engineering completion.

Research Gaps and Future Research:-

First there are no comparable field studies that measure quality adjusted cycle time for E&I commissioning. Future multi-case work should match systems or match phased deployment periods and report on the baseline differences. Second, the reliability of automatically captured test readings under conditions of dust, heat, intermittent connectivity and the difficulties of accessing areas that are hazardous is not well understood. Controlled field trials are required to compare manual transcription, offline first capture and direct instrument integration against independently verified reference records.

Thirdly the research should look at whether digital handover leads to a reduction in operational troubleshooting post start up with a particular focus on tag reconciliation, reconfigured controllers and punch items that remain unresolved. Fourthly there is a need for cybersecurity research to develop commissioning specific threat scenarios (e.g. temporary contractor accounts, vendor laptop connections, version control of protective settings). Lastly mixed methods research in the Saudi context should look at competence, trust, language accessibility, the incentives for subcontractors and ownership of the electronic evidence. These are all hypotheses to test, not pre-existing local deficits.

Research designs should where possible pre-register outcomes, maintain anonymised audit trails and clearly separate fault discovery from fault prevention. Economic evaluations should incorporate configuration effort, instrument integration, licensing, training, cyber assurance and the cost of long term data stewardship. Independent replication would be particularly useful given that there is a clear incentive for both the vendor and the project owner to select the implementation examples that are most favourable to them.

Another key priority is agreement on what the outcomes are. The study should define and report on initial test completion, first pass acceptance, provisional readiness, subsystem turnover and final operating acceptance. Denominators and the way retests are treated should be published rather than just the attractive looking percentages. Negative cases (where deployment was abandoned, connectivity failed, migration resulted in inconsistent asset identifiers etc) would be of considerable value in terms of understanding the limits and avoiding publication bias.
Long term research could look at the evidence defects identified in the first year of operation and work backwards to the commissioning records. That would take the assessment beyond the construction schedule and would allow you to see whether the apparently complete dossiers actually assist with fault finding. You'd obviously need agreed definitions of what constitutes missing documentation, contradictory settings and undetected installed defects. That would be a difficult study to run as operational changes can completely wash out the historical responsibility, but it would be a study that would test the very premise of lifecycle continuity.

Evidence on technician interaction should be collected in parallel with the platform metrics. Field observation can tell you whether screens are actually distracting during high risk tasks, whether the barcode tags are still legible after exposure and whether offline sync is in fact creating duplicate records. The interview data will tell you why people go around the controls but that needs to be corroborated with the time-stamped events and the actual observed behaviour. The adoption surveys will tell you what people think but will not tell you whether the actual commissioning evidence that they have produced is correct.

Practical, Managerial and Policy Implications:-

Project owners must define the information requirements of the commissioning dossier prior to procurement. This will include equipment identifiers that are consistent throughout, the ability to link document revisions, inspection hold points, the use of electronic signatures (and which ones are acceptable), instrument calibration evidence, defect status and the format of the handover that can be exported. Contractors should not be paid simply for closing the digital tasks; contractual acceptance of the work should be predicated on the ability to retrieve proof that each of the required tests has been completed against the correct configuration. Table 2 sets out these requirements in terms of the responsibilities of the owner, the contractor and the governance structure.

Table 2. Implementation responsibility and suggested evaluation measures (author synthesis)

Responsible party	Implementation commitment	Observable audit measure
Owner / operator	Define tag schema, handover attributes and final acceptance rights	Completeness of required asset evidence

EPC / commissioning contractor	Implement approved procedures, checks and exception closure	Traceable first-pass acceptance and retest history
Quality and metrology	Verify instrument status, limits, witness and audit records	Calibration-linked accepted test proportion
IT / OT security	Control connected devices, accounts and data pathways	Unresolved access or configuration deviations
Project leadership	Fund training, pilot validation and lifecycle stewardship	Retrieval time and rejected handover package rate

Implementation should be staged. Start with a small sample of loops, switchboards and safety related interfaces. Reconcile the design tags with the installed tags. Validate the forms against the approved test procedures. Introduce the device connections only after you've done the cyber security and metrology checks. For the field teams the issues may well be mobile offline operation, the use of Arabic and English where appropriate, ergonomics of entry and clear escalation paths rather than any kind of AI. Training should be on how to spot invalid evidence rather than simply where to hit the approval button.

Management teams need to have joint accountability between commissioning, quality, instrument specialists, electrical engineering, operations and cybersecurity. The digital lead may be responsible for platform configuration but should not have the power to unilaterally overrule technical acceptance. Policymakers and the sector bodies could provide support in the form of interoperable data conventions, vocational digital metrology capability and privacy aware evidence retention. Any proposed alignment with Saudi regulations or owner standards must be checked against the current applicable contract and regulatory provisions. This review in no way purports to be a statement of legal compliance.

Procurement specs can make interoperability something that can be assessed rather than just talked about. The vendor needs to be able to demonstrate structured export of readings and sign-offs, stable tag identifiers, role based approvals, retention of superseded versions and the ability to recover records after disconnection. Acceptance testing of the digital platform itself should include incorrect calibration certificates, duplicate tags, rejected measurements, unauthorised access attempts and post test design changes. Each of those scenarios must fail in a safe manner, generate a reviewable exception and prevent the silent promotion to 'completed'.

Digital procedures should be set up to deal with the replacement of test equipment during the course of an activity. If a tester fails or is replaced the system must maintain the original instrument identity, identify which readings are still valid and which will require a re-measurement. The same applies when engineering drawings change. The acceptance package should record the revision that was reviewed and automatically flag any tests that may be affected for engineering disposition. That's safer than just having the person walk in and overwrite the existing record with their new values.

Senior management can of course commission independent acceptance audits of the digital system prior to key startup milestones. The auditors would sample asset tags from the physical plant, trace them through the engineering registers to the signed test results and back to the installed configuration. The sampling must include the failed, deferred and retested cases as well as the closed cases. A system that is able to preserve the exceptions in a sensible way is far more credible than one that merely presents a series of green aggregate indicators.

The responsible review authority should record the reason for any accepted exceptions and decide whether the deferred tests will in any way impact energisation or startup. Evidence of retention should include the decisions, their justifications and the responsible signatories. This provides the operator with an accountable record of conditional acceptance rather than simply an electronic 'completion' status without any explanation.

Limitations:-

The evidence presented is very disparate and is overwhelmingly skewed towards the adjacent domains rather than any actual Saudi E&I commissioning work. A targeted integrative approach cannot be used to establish the completeness of the global literature. There are no database specific record counts, no duplicate screening, no independent quality scores and no pooled effect sizes claimed. There is a very significant amount of heterogeneity in

terms of project type, software architecture and industrial regulation which will limit transferability. The diagrams and tables are original conceptual syntheses and not validated standards or results from a Saudi field trial.

Conclusion:-

Digital transformation of E&I inspection, testing and commissioning is really about reconfiguring the technical evidence and the acceptance authority. The opportunities are clear in the areas of digital records, connected instruments, integration of asset information and the ability to run analytical checks. The opportunities are only realised if identity, configuration, calibration, cybersecurity and independent authorisation are all maintained. The literature is far more supportive of the potential for improved traceability and information continuity than it is of any specific numerical claims about Saudi commissioning productivity. An evidence based, stage-gated approach is a sensible starting point for implementation and assessment. The real test of value will be in the field, in terms of actual commissioning outcomes, lifecycle defect escape and the total cost of information governance over the life of the asset.

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