SUPPLY CHAIN MANAGEMENT

Enterprise Digitalization and Intelligent Workflow Automation for Improving Supply Chain Workforce Productivity in Saudi Arabia's Energy Sector

Hashim Hussain

Published November 2026

Abstract

Enterprise digitalisation has become integral to procurement, materials planning and maintenance coordination, yet its contribution to employee productivity in energy supply chains remains poorly specified. This review examines how intelligent workflow automation changes the work of buyers, expeditors, planners, warehouse specialists and asset support personnel in Saudi Arabia. A structured, critically bounded synthesis of thirty peer-reviewed studies published between 2020 and 2025 compares process automation, digital integration, human decision rights and performance measurement. Rather than equating faster transactions with productivity, the analysis distinguishes task throughput, first-time-right quality, decision latency and resilience. It identifies three mechanisms of potential benefit: removing clerical handovers, improving cross-functional information reliability and directing professional attention towards consequential exceptions. However, fragmented master data, unstable business rules and poorly designed oversight can displace rather than eliminate work. The paper develops a risk-calibrated workflow framework that links data stewardship, automation boundaries and worker competence to measurable operational outcomes. Its contribution is an energy-specific explanation of when automation augments supply chain labour, alongside a testable implementation and research agenda for Saudi organisations.

Keywords: enterprise digitalisation; intelligent workflow automation; supply chain workforce productivity; energy sector; procurement; Saudi Arabia; process governance

1 Introduction

An energy supply chain does not operate as a simple sequence of purchase, delivery and payment. The availability of a replacement valve may depend on engineering verification, supplier certification, export documentation, inspection release, customs clearance, warehousing and maintenance scheduling. Each interface brings specialised expertise and a possible point of delay. Digital integration can reveal the status of these dependencies, while software automation can move documents and validate routine fields. Whether the people responsible become more productive depends on what happens to the exceptions that remain. An accelerated approval is not a gain when it causes rework or permits the wrong material to reach a critical asset.

Research on digital transformation in resource and energy industries establishes both the potential for connected operations and their relatively demanding implementation conditions [1]. Roadmapping studies of offshore exploration supply chains show that enterprise change requires an explicit pathway from existing work to the desired operating model, not a software-first deployment [2]. Human-centred research additionally identifies the risk of treating workers only as factors in an efficiency calculation [3]. Together these contributions support a narrower question: which changes

to information, task allocation and decision authority actually increase the useful productive capacity of supply chain personnel?

The Saudi setting gives this question distinctive importance. Large industrial assets, remote facilities, project-based purchasing, local supplier development and the coordination of hydrocarbon and emerging energy operations create heterogeneous workloads. Vision 2030 places importance on industrial capability, digital innovation and workforce development. These ambitions are relevant to this review as policy context, not as empirical evidence that any particular algorithm improves productivity. National benefit must be demonstrated through reliable delivery, capability transfer and verifiable outcomes.

The paper makes three contributions. First, it distinguishes routine transaction automation from intelligent decision support in high-consequence energy workflows. Second, it explains why integration quality and human decision rights mediate productivity gains. Third, it offers an operational measurement scheme capable of separating reduced effort from work transferred between departments. This framing complements broader studies of digital supply chains while maintaining energy-specific attention to safety, asset criticality and contractual accountability.

2 Aim, objectives and questions

The aim is to evaluate how enterprise digitalisation and intelligent workflow automation can improve quality-adjusted supply chain workforce productivity in Saudi Arabia's energy sector without weakening control of high-consequence decisions. Five objectives structure the review: to establish the mechanisms through which digital systems alter task effort; to distinguish automatable routines from decisions requiring professional interpretation; to analyse interfaces among purchasing, materials management and asset maintenance; to specify workforce and governance conditions for sustainable adoption; and to develop indicators and research propositions suitable for Saudi operational trials.

Three research questions follow. RQ1 asks which workflow characteristics determine whether automated execution or human-supported judgement is appropriate. RQ2 investigates how information interoperability, employee capability and escalation arrangements influence the quality of procurement and materials decisions. RQ3 considers how organisations can identify net productivity gains after accounting for correction work, system supervision and resilience obligations. The questions are deliberately different from a technology inventory: the explanatory object is the changed work system, not the number of installed applications.

3 Theoretical basis and analytical distinction

Digitalisation, digitisation and automation describe different changes. Digitisation converts records into digital form; enterprise digitalisation reorganises information and coordination across functions; automation executes specified steps without direct human input. Intelligence adds classification, prediction or recommendation, but does not necessarily change where responsibility lies. A supplier screening model may flag irregular documents, for example, without being authorised to approve a source for safety-critical equipment. Treating these stages as interchangeable makes it impossible to identify what produced a performance improvement [4,5].

The review combines a sociotechnical interpretation of work design with information processing and dynamic capability arguments. Transaction records matter only when they are sufficiently consistent

for useful interpretation. Organisational capabilities matter because changes in software seldom remove departmental handovers automatically. Resilience matters because a highly efficient automated process may fail when an external portal is unavailable, an order involves an unusual specification or a shipment is rerouted. Evidence on supply chain digitalisation indicates that technology maturity and actual tool adoption should be distinguished [6,7].

A useful distinction is between task productivity and system productivity. Task productivity refers to completing an individual step with fewer inputs; system productivity concerns achieving the intended operational result with less total effort, better quality or greater reliability. Eliminating manual data entry can improve the first while leaving supplier queries and invoice disputes unchanged. The second requires mapping the entire requisition to availability chain. Studies of purchasing automation describe substantial potential alongside readiness, process selection and implementation barriers [4,8]. Consequently, the review treats productivity as a conditional result of coherent work design.

4 Review design and methodological boundaries

This article uses a structured critical integrative review. The unit of synthesis is the organisational mechanism connecting digital tools with work practices, rather than an estimated average technology effect. Searches for relevant literature used combinations of “energy”, “oil and gas”, “procurement”, “supply chain”, “workflow automation”, “robotic process automation”, “process mining”, “digital twin”, “workforce”, “productivity” and “Saudi Arabia”. Publication dates were restricted to 2020–2025. Searches of publisher records and scholarly metadata were supplemented by checking relevant reference trails. Thirty DOI-linked journal articles were selected for detailed conceptual comparison.

The inclusion logic favoured work addressing one or more of four interfaces: enterprise information integration, automated procurement or logistics processes, energy asset coordination, and workforce or operational outcomes. Papers focused exclusively on predicting a physical signal without a plausible work process implication were not central. The corpus deliberately includes energy-specific research and transferable evidence from logistics, business process management and production planning. This provides conceptual breadth, but evidence from another industry is labelled as transferable rather than presented as a Saudi field observation.

For each contribution, the synthesis considered study setting, research design, technology class, task boundary, human role, outcome definition and limits to transferability. Findings were compared through four analytical themes: process selection, information reliability, risk-calibrated human control and performance evaluation. Contradictions were retained. For example, positive findings for automation of stable procurement steps [5] do not justify autonomous decisions on technical substitution. Conceptual arguments were differentiated from observed effects, and studies reporting organisational associations were not treated as proof of causation.

This is not a claim of an exhaustive indexed database census or a meta-analysis. No fabricated screening totals, quality coefficients or pooled effect sizes are supplied. The thirty-item corpus permits a reproducible bibliography and transparent synthesis logic, but further exhaustive searching and independent screening would be necessary before presenting it as a fully systematic coverage of the field. Such candour is particularly important when judging an emerging intersection for which direct Saudi workplace experiments are sparse [9,10]. The review does not assign numerical quality scores to studies without a predeclared appraisal instrument and independent coding record

5 Enterprise information architecture

Energy supply chain employees commonly work across enterprise resource planning, supplier portals, equipment registers, warehouse systems, maintenance software and contract repositories. Each application may represent the same asset, supplier or delivery milestone differently. Intelligent automation built on inconsistent identifiers is vulnerable to silent error. A script can copy a purchase order rapidly but cannot determine that two catalogue descriptions refer to incompatible grades of material unless appropriate semantics and controls exist. Data stewardship is therefore a productivity intervention, not an administrative preliminary task.

An effective architecture distinguishes reference information from transactional events. Material master data should define approved specifications, unit conversions, criticality and substitution rules; transaction data should show what changed, when, why and by whose authority. Shared identifiers connect a maintenance notification to a material reservation, procurement action, shipment record and site receipt. The digital twin literature demonstrates the value of linking operational states and scenario information, but also documents the difficulty of reconciling heterogeneous sources and infrastructure choices [11,12]. Such systems should not be mistaken for an automatic solution to weak data governance.

Connectivity decisions must reflect operating constraints. Cloud services offer shared access, whereas local processing may support time-sensitive or disconnected facilities. Their relative merits depend on security, latency and continuity requirements, not on a universal ranking [12]. Interoperability should also reach suppliers and inspection contractors; otherwise employees continue to reconcile PDFs and email updates outside the formal workflow. The decisive question is whether authorised personnel can act upon a trustworthy common version of the process. Visibility without shared definitions can simply distribute disagreement faster. Figure 1 summarises the proposed pathway from information reliability to workforce productivity. A formal data dictionary can also prevent similar labels from disguising different meanings across warehouses, projects and maintenance departments.



Figure 1. Conceptual pathway from information reliability to quality-adjusted workforce productivity.

6 Intelligent purchasing and supplier qualification

Purchasing offers mature automation opportunities because many steps are frequent and rule-based. A well-bounded service can extract invoice fields, compare quotations against catalogue rules, verify document completeness, route requests to authorised approvers and create an exception record. A documented procurement implementation shows that successful automation depends on process stability, governance and institutional learning rather than technical configuration alone [5]. Multiple-case evidence also highlights data readiness and barriers to translating potential into operational value [4].

Supplier qualification reveals the boundary. Validating the presence and expiry of a certificate is not equivalent to judging whether the certified facility can manufacture the required component. In energy operations, technical equivalence, inspection obligations, provenance and contractual risk may require expert interpretation. AI and machine learning reviews identify promising purchasing applications but also a mismatch between research attention and practitioners' operational priorities [9,13]. This strengthens the case for separating automated checks from accountable source approval. A risk score can direct a buyer's attention; it should not silently replace the buyer's professional judgement.

Process design ought to identify the evidence needed for each decision and the escalation path when that evidence is missing. Requests involving routine consumables may proceed through straight-through validation; unusual specifications, sanctions indicators or sensitive payment changes should trigger deliberate review. If a robotic system produces a nominally faster supplier registration but increases downstream disputes, its net labour benefit is negative. Evaluation should record not only registration duration but also clarification cycles, correction hours and supplier accessibility.

A further practical issue is supplier master data modification. Changes to bank accounts, manufacturing sites or legal registrations are relatively infrequent but potentially consequential. Automated comparison can identify inconsistent identifiers or missing corroboration, while independent verification remains necessary for sensitive amendments. Control design should therefore classify the transaction by reversibility and potential loss. A bot that processes thousands of ordinary records should not inherit authority over all amendments simply because they appear in the same application. This distinction protects commercial integrity while allowing routine work to be completed promptly.

7 Materials planning and maintenance interdependence

Supply chain productivity in energy organisations depends heavily on the coupling between maintenance priorities and material availability. Critical spares are not ordinary stock-keeping units: their value depends on failure consequences, replacement lead times, shelf life and compatibility with an installed asset. A demand model may identify inventory exposure, yet a mechanical engineer must still decide whether an alternative part is appropriate. Integrating maintenance planning and supply decisions under uncertainty has demonstrated the importance of treating these schedules as connected decisions rather than isolated optimisation problems [14].

An intelligent materials workflow can link planned work orders to reservations, indicate risks of late delivery and prioritise expediting according to asset criticality. It can also flag discrepancies between the authorised bill of materials and purchase descriptions. Digital twins have been tested in oil and gas-related manufacturing to compare production scenarios and improve internal coordination [11,15]. Such evidence supports the potential of integrated planning, although it should not be interpreted as proof of equivalent gains in every upstream Saudi facility.

An important tension emerges between inventory efficiency and operational assurance. Reducing stock may improve working capital while exposing facilities to prolonged downtime. Conversely, automated replenishment based on noisy demand could generate redundant purchases or premature stock accumulation. A credible productivity assessment combines planner effort with work order readiness, emergency freight expense, avoidable stockouts and time to resolve shortages. The unit of performance is successful maintenance support, not merely the speed at which a request travels through a system.

Table 1 summarises the automation boundaries for the main energy supply chain workflows. Shutdown planning illustrates these dependencies clearly. A replacement component may arrive on schedule yet be unusable because test certificates were not accepted or an inspection was not completed. Conversely, an apparently delayed item may no longer be required after the maintenance scope changes. Digital coordination is valuable when it reconciles purchase commitments with the latest approved work package. Escalations should reflect remaining schedule float, consequence of failure and the practicality of alternative sourcing. Operational employees then spend attention on meaningful uncertainties rather than repeatedly requesting status updates.

Table 1. Energy supply chain workflows, automation boundaries and retained professional responsibility.

Work process	Automatable step	Human decision boundary	Failure consequence
Supplier qualification	Check document completeness and dates	Technical acceptability and legal integrity	Unqualified source accepted
Critical spares	Flag shortages against approved work	Approve equivalent materials and urgency	Equipment unavailability
Inbound logistics	Reconcile milestones and receipt records	Resolve hazardous cargo and site restrictions	Unsafe or unusable delivery
Invoice matching	Match approved order, receipt and invoice	Investigate disputed amounts and exceptions	Payment error or supplier dispute

8 Logistics, documents and exception handling

Energy logistics frequently involves specialised handling, cross-border documentation, site access windows and inspection releases. Digital transport messages can improve traceability, but interface proliferation may create additional work when carriers, customs agents and site contractors use incompatible systems. The most defensible approach is to automate stable clerical exchanges while designing explicit routes for nonstandard cases. Research on robotic automation in logistics highlights the difference between identifying potential tasks and building durable services within operational organisations [8].

Process mining can expose where orders wait, return for correction or pass repeatedly between departments. Event log analysis is especially valuable where managers believe a process is standardised but workers actually rely on informal workarounds. Nevertheless, software traces omit phone calls, contextual negotiations and physical inspections. Research on robotic process mining emphasises the need to connect observed digital activity with genuine task meaning [16,17]. Studies of process mining adoption similarly demonstrate that management questions extend from tool selection to sustained governance and use [18].

Exception management should be designed rather than inherited. A missing vendor document, an unusual hazardous goods code, an inaccessible delivery location and an equipment substitution are different problems. Each needs an appropriate owner, evidence set and response time. Grouping them as generic “failed transactions” can overwhelm senior specialists. A useful digital queue therefore provides cause, consequence, decision history and next action. The productivity gain comes from reducing investigation time while preserving the checks that make a shipment safe and usable.

9 Workforce productivity and job redesign

Automation changes the distribution of work. Administrative steps may disappear while verification, exception diagnosis, interface maintenance and model supervision expand. A procurement analyst might spend less time copying catalogue data but more time addressing ambiguous supplier classifications. A planner may receive better shortage warnings yet face additional alerts that compete for attention. Net productivity cannot be established by counting bot transactions or comparing the manual portion of a process before and after automation. Reviews of digital supply chain metrics underline the need for broader measurement beyond narrow financial and internal indicators [19].

Human-centred energy research provides a corrective to technology-first evaluation by positioning employees' safety, working conditions and practical constraints within transformation design [3]. Trust also requires organisational legitimacy. Workers should know which decisions are delegated, how their overrides are reviewed and whether system errors will be attributed fairly. An application that hides uncertainty encourages overconfidence; one that requires constant checking without improving information quality may increase cognitive burden. These tensions are consistent with recent research on AI adoption in planning, which describes conflicts among standardisation, flexibility, identity and skills [20].

Workforce design should differentiate roles rather than promise generic digital literacy. Buyers need to interpret commercial and contractual exceptions; engineers must verify material suitability; expeditors need evidence-based milestone management; warehouse personnel need traceable identification and safe handling procedures. Training therefore includes data interpretation, failure diagnosis and decision authority as well as software navigation. Performance assessment should report workload intensity and overtime alongside throughput, because a faster process is not necessarily a more sustainable workplace.

The distribution of benefits also matters. Experienced buyers may become the default destination for every difficult exception, increasing cognitive pressure even as junior colleagues complete fewer routine checks. If entry-level tasks vanish entirely, opportunities to acquire basic commercial and technical knowledge may diminish. Organisational development plans should address progression through supervised exceptions, structured mentoring and explicit competency assessments. Productivity improvements achieved through unsustainable concentration of difficult work are unlikely to endure. Monitoring should therefore compare escalation volume with available specialist capacity and record whether overrides are treated as useful professional feedback.

10 A risk-calibrated productivity framework

The framework in Figure 1 is a proposed mechanism rather than measured causal effects. Its first layer is dependable information: common identifiers, validated documents, accessible event histories and cybersecurity controls. The second comprises workflow mechanisms: routine validation, predictable routing, exception prioritisation and decision support. The third concerns human capability: role-specific skills, accountable overrides and cross-functional coordination. Outcomes appear only at the final layer, where speed, quality, service readiness and resilience can be measured together. The framework implies that high automation coverage with weak information quality is unlikely to produce durable system-level gains.

Risk determines the proper degree of autonomy. Reversible, low-consequence administrative activities are candidates for unattended execution with sampling. Transactions involving uncertain supplier

identity, technical substitution or safety consequences require explicit professional authorisation. This is not a retreat from digitalisation: concentrating skilled attention on consequential choices is an important form of productivity. Wider supply chain evidence suggests that digital assets improve performance through visibility, agility and supporting capabilities rather than by their presence alone [6,21,22].

The model makes falsifiable claims. A workflow with clearer master data should produce fewer avoidable escalations, all else equal. A better designed exception interface should reduce investigation effort without increasing compliance failures. A process redesigned across procurement and maintenance should outperform a locally automated purchasing step when measured by material readiness at the worksite. These propositions can be tested, but should not be presented as confirmed relationships in Saudi enterprises before operational evidence is collected. Figure 2 sets out the staged implementation pathway.

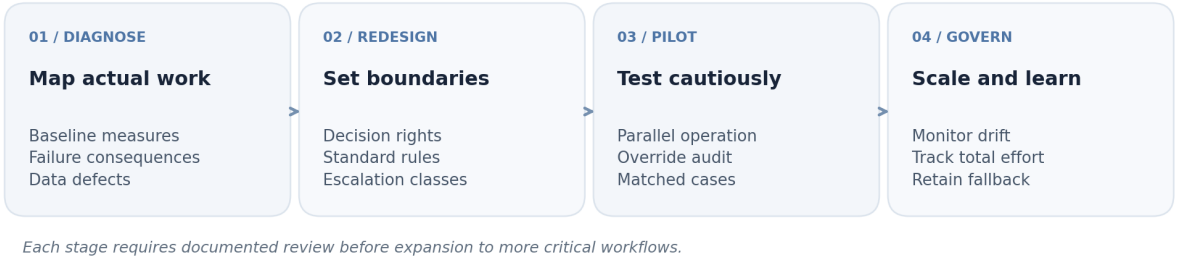


Figure 2. Staged implementation pathway with explicit controls and learning feedback.

11 Governance, implementation and measurement

Automation governance should begin with a decision inventory: which events trigger action, which facts are required, which risks are tolerable and who retains authority. The literature on business process automation identifies human, organisational and technical factors as jointly important to implementation success [10]. Process digitalisation research likewise cautions against treating projects as purely technical installations. Governance must extend through design, testing, release management and periodic review.

A staged approach is therefore preferable. First, establish baseline process boundaries and audit data defects. Second, standardise the most frequent routine decisions while protecting necessary control points. Third, pilot a limited workflow with named owners and explicit reversal procedures. Fourth, assess the whole service chain before scaling. Figure 2 translates these stages into an implementation cycle; the order is not mandatory for every firm, but the underlying evidence checks should be retained. A roadmap tailored to energy operations should account for physical asset consequences and supplier dependence [2].

Productivity measurement requires matched denominators. A fall in average manual handling time may merely mean that simple tasks have been automated, leaving unusually difficult cases with staff. Comparisons should stratify cases by complexity and urgency, include the hours spent correcting mistakes, and measure successful end outcomes. Table 2 proposes a balanced indicator set. It includes first-time-right completion, end-to-end cycle time, critical material readiness, escalation age and employee burden. Researchers should also examine whether gains arise from transferring unpaid effort to suppliers or other departments. A robust business case incorporates maintenance cost, cybersecurity assurance and fallback capacity.

Resilience testing should expose workflows to plausible operating disruptions. These include loss of connectivity at a remote facility, failure of a supplier interface, contradictory material data and sudden changes to maintenance priorities. A reliable implementation documents how transactions are paused, reconciled and resumed without losing approval history. Recovery procedures are an integral part of productivity because a process that saves routine labour but collapses during critical demand may increase total organisational cost. Evaluators should measure recovery effort and reconciliation quality alongside normal cycle time.

Table 2. Proposed indicators for evaluating net workforce productivity in energy supply chains.

Dimension	Indicator	Measurement principle	Interpretive caution
Efficiency	Case-adjusted end-to-end cycle time	Request to usable site delivery	Exclude unavoidable assurance delay
Accuracy	First time right completion	No correction or repeat validation	Do not hide supplier rework
Service	Critical material readiness	Approved item available before work	Consider material criticality
Workforce	Net-person-hours per completed case	Include monitoring and escalations	Account for shifted labour
Resilience	Time to recover from workflow outage	Test fallback and reconciliation	Separate normal and disrupted cases

12 Saudi energy sector implications

Saudi energy enterprises face a combination of global sourcing, significant infrastructure investment and the development of domestic capabilities. These conditions make automation an attractive means of coordinating documents and milestones across organisational boundaries. Yet a large enterprise can deploy sophisticated platforms while smaller suppliers remain dependent on manual uploads. Imposing costly interfaces without transition support could reduce supplier diversity and inadvertently concentrate procurement. Inclusive digitalisation should therefore allow structured portals and standard documents alongside more advanced system integration.

The policy relevance of Vision 2030 lies in the combination of industrial upgrading and human capital development. A meaningful evaluation asks whether digital projects improve professional skills, dependable local supply and the ability to recover from disruption. Energy facilities also vary in network connectivity, operating criticality and contracting structures; a headquarters pilot may not represent remote site conditions. Saudi studies should record those characteristics rather than invoke the national strategy as sufficient evidence of success.

Cross-functional sponsorship is essential. Procurement, asset integrity, maintenance, finance, information security and workforce development should share ownership of the redesign. Sustainability considerations reinforce this need: digital visibility can reduce emergency shipping, but faster ordering may also create smaller and more frequent consignments. Research on digital supply chains and sustainable performance provides reasons to examine environmental and economic objectives jointly [23]. National competitiveness will depend upon reliable coordination, not an isolated count of automated tasks.

13 Critical discussion

The evidence base provides reasons to expect benefits from selected forms of workflow automation, but causal certainty is uneven. Procurement case studies are operationally informative, yet local success may depend on unusually stable procedures or committed implementation teams [4,5]. Survey studies connect digital capabilities with supply chain performance, but often rely on organisational perceptions rather than observed employee time use [24–26]. Engineering models demonstrate the feasibility of integrated planning, without necessarily showing how personnel respond when a system is deployed under live operational pressure [11,14]. These designs answer different questions and should not be collapsed into one performance claim.

The principal theoretical implication is that digitalisation changes how work is allocated across a network. Rather than replacing a single administrative activity, it shifts information processing, decision authority and accountability between participants. A performance gain at one desk can coexist with increased work in engineering, compliance or supplier support. This explains why local automation projects sometimes fail to deliver end-to-end improvement despite strong technical performance. The argument is consistent with research emphasising smart technologies, organisational relationships and resilience rather than mere digitisation [7,27–29].

Three trade-offs deserve attention. The first is speed against assurance: automated approvals are valuable only within justified risk boundaries. The second is standardisation against flexibility: rules permit scale, but unusual equipment and operational disruptions require expert discretion. The third is transparency against overload: broader information visibility is helpful only when the worker can identify actionable signals. These are design problems, not permanent reasons to reject automation. Their resolution requires operational testing, transparent governance and interdisciplinary evidence.

14 Research gaps and future studies

The greatest empirical gap is direct measurement of Saudi energy supply chain work before and after digital integration. Available literature often assesses technology readiness, firm-level capability or simulated performance. Future studies should combine event logs, shadowing of employee tasks and operational outcome records. A staged rollout across comparable sites could provide a stronger counterfactual than a retrospective survey, provided concurrent staffing and demand changes are documented. Researchers should specify whether a reported saving arises from automation, changed business rules or simple elimination of unnecessary approvals.

Further research should address the accuracy of escalation thresholds, the cost of maintaining automated rules and the consequences of overreliance on recommendations. Workers may accept an erroneous classification because it appears authoritative, or reject a useful suggestion because previous failures damaged trust. Interviews alone cannot resolve these alternatives; researchers should observe override behaviour and subsequent outcomes. Studies of human-centred technology and AI adoption offer relevant constructs but cannot substitute for energy-specific field tests [3,20,30].

Comparative research should also include supplier-side effects and smaller domestic firms. Interoperability investments may benefit dominant operators while creating compliance costs for contractors. Multi-actor studies can investigate whether shared standards improve participation, data quality and resilience. Finally, research should examine whether digital work redesign creates genuine career progression or merely raises output expectations. The contribution of intelligent automation to Saudi

capability development is a substantive empirical question, not an automatic consequence of adopting advanced systems. Evidence matters.

15 Limitations

The review uses a purposively bounded set of thirty journal articles rather than an independently screened census of all records in bibliographic databases. Its thematic conclusions are interpretive, not pooled estimates. Some cited research concerns manufacturing, maritime procurement or general supply chains; its application to Saudi energy operations requires qualification. The review does not have access to confidential purchasing event logs, workforce observations or supplier contracts, and therefore does not claim verified Saudi productivity improvements. Publication bias and uneven reporting of unsuccessful projects may also affect the available evidence. These constraints limit inference but support a focused programme of operational testing.

16 Conclusion

Enterprise digitalisation can improve supply chain workforce productivity in Saudi Arabia's energy sector when it reduces avoidable handovers, strengthens the reliability of shared information and reserves skilled judgement for consequential exceptions. The evidence does not support treating automation volume or software adoption as a substitute for operational value. Productivity must be evaluated through complete work outcomes, including first-time-right material availability, employee effort, quality and resilience. The proposed framework joins data stewardship, risk-calibrated automation and workforce capability in an evaluable sequence. Its value should be established through comparative Saudi field studies in procurement, maintenance-linked materials planning and logistics coordination. Future investments should prioritise trustworthy processes and professional decision making over technology acquisition alone.

References

[1] Maroufkhani P, Desouza KC, Perrons RK, Iranmanesh M. Digital transformation in the resource and energy sectors: A systematic review. *Resources Policy*. 2022;76:102622. https://doi.org/10.1016/j.resourpol.2022.102622

[2] Czachorowski KV, Haskins C. Applying systems engineering to roadmapping for digital transformation in the offshore exploration and production supply chain operations. *Systems Engineering*. 2022;25:191–206. https://doi.org/10.1002/sys.21611

[3] Wanasinghe TR, Trinh T, Nguyen T, Gosine RG, James LA, Warrian PJ. Human-centric digital transformation and Operator 4.0 for the oil and gas industry. *IEEE Access*. 2021;9:113270–113291. https://doi.org/10.1109/ACCESS.2021.3103680

[4] Flechsig C, Anslinger F, Lasch R. Robotic process automation in purchasing and supply management: A multiple case study on potentials, barriers, and implementation. *Journal of Purchasing and Supply Management*. 2022;28:100718. https://doi.org/10.1016/j.pursup.2021.100718

[5] van Hoek R, Larsen JG, Lacity M. Robotic process automation in Maersk procurement: Applicability of action principles and research opportunities. *International Journal of Physical Distribution & Logistics Management*. 2022;52:285–298. https://doi.org/10.1108/IJPDLM-09-2021-0399

[6] Zouari D, Ruel S, Viale L. Does digitalising the supply chain contribute to its resilience? *International Journal of Physical Distribution & Logistics Management*, 51, 149–180. 2021. https://doi.org/10.1108/IJPDLM-01-2020-0038

[7] Nasiri M, Ukko J, Saunila M, Rantala T. Managing the digital supply chain: The role of smart technologies. *Technovation*. 2020;96–97:102121. https://doi.org/10.1016/j.technovation.2020.102121

[8] Tsang YP, Tang V, Wu CH, Li F. Unlocking the potential of robotic process automation for digital transformation in logistics and supply chain management. *Journal of Global Information Management*. 2024;32:1–24. https://doi.org/10.4018/JGIM.361710

[9] Spreitzenbarth JM, Bode C, Stuckenschmidt H. Artificial intelligence and machine learning in purchasing and supply management: A mixed-methods review of the state of the art in literature and practice. *Journal of Purchasing and Supply Management*. 2024;30:100896. https://doi.org/10.1016/j.pursup.2024.100896

[10] Schlegel D, Rosenberg B, Fundanovic O, Kraus P. How to conduct successful business process automation projects? An analysis of key factors in the context of robotic process automation. *Business Process Management Journal*. 2024;30:99–119. https://doi.org/10.1108/BPMJ-06-2023-0465

[11] Cimino A, Longo F, Mirabelli G, Solina V, Veltri P. Enhancing internal supply chain management in manufacturing through a simulation-based digital twin platform. *Computers & Industrial Engineering*. 2024;198:110670. https://doi.org/10.1016/j.cie.2024.110670

[12] Knebel FP, Trevisan R, Nascimento G, Abel M, Wickboldt JA. A study on cloud and edge computing for the implementation of digital twins in the oil and gas industries. *Computers & Industrial Engineering*. 2023;182:109363. https://doi.org/10.1016/j.cie.2023.109363

[13] Osmonbekov T, Johnston WJ, Donthu N. Artificial intelligence advancements in procurement: Transforming organizational buying behavior. *Journal of Business & Industrial Marketing*. 2024;39:2745–2758. https://doi.org/10.1108/JBIM-01-2024-0026

[14] Attia AM. Integrated risk management and maintenance planning in oil and gas supply chain operations under market uncertainty. *Computers & Chemical Engineering*. 2025;192:108879. https://doi.org/10.1016/j.compchemeng.2024.108879

[15] Wang T, Feng K, Ling J, Liao M, Yang C, Neubeck R, et al. Pipeline condition monitoring towards digital twin system: A case study. *Journal of Manufacturing Systems*. 2024;73:256–274. https://doi.org/10.1016/j.jmsy.2024.02.006

[16] Leno V, Polyvyanyy A, Dumas M, La Rosa M, Maggi FM. Robotic process mining: Vision and challenges. *Business & Information Systems Engineering*. 2021;63:301–314. https://doi.org/10.1007/s12599-020-00641-4

[17] El Gharib NM, Amyot D. Robotic process automation using process mining: A systematic literature review. *Data & Knowledge Engineering*. 2023;148:102229. https://doi.org/10.1016/j.datak.2023.102229

[18] Grisold T, Mendling J, Otto M, vom Brocke J. Adoption, use and management of process mining in practice. *Business Process Management Journal*. 2021;27:369–387. https://doi.org/10.1108/BPMJ-03-2020-0112

[19] Rasool F, Greco M, Grimaldi M. Digital supply chain performance metrics: A literature review. *Measuring Business Excellence*. 2022;26:23–38. https://doi.org/10.1108/MBE-11-2020-0147

[20] Jazairy A, Shurrab H, Chedid F. Impact pathways: Walking a tightrope—unveiling the paradoxes of adopting artificial intelligence in sales and operations planning. *International Journal of Operations & Production Management*. 2025;45:1–27. https://doi.org/10.1108/IJOPM-07-2024-0582

[21] Ye F, Liu K, Li L, Lai KH, Zhan Y, Kumar A. Digital supply chain management in the COVID-19 crisis: An asset orchestration perspective. *International Journal of Production Economics*. 2022;245:108396. https://doi.org/10.1016/j.ijpe.2021.108396

[22] Valle Enrique D, Lerman LV, de Sousa PR, Benitez GB, Santos FMBC, Frank AG. Being digital and flexible to navigate the storm: How digital transformation enhances supply chain flexibility in turbulent environments. *International Journal of Production Economics*. 2022;250:108668. https://doi.org/10.1016/j.ijpe.2022.108668

[23] Winkelmann S, Guennoun R, Möller F, Schoormann T, van der Valk H. Back to a resilient future: Digital technologies for a sustainable supply chain. *Information Systems and e-Business Management*. 2024;22:315–350. https://doi.org/10.1007/s10257-024-00677-z

[24] Hallikas J, Immonen M, Brax S. Digitalizing procurement: The impact of data analytics on supply chain performance. *Supply Chain Management: An International Journal*. 2021;26:629–646. https://doi.org/10.1108/SCM-05-2020-0201

[25] Qader G, Junaid M, Abbas Q, Mubarik MS. Industry 4.0 enables supply chain resilience and supply chain performance. *Technological Forecasting and Social Change*. 2022;185:122026. https://doi.org/10.1016/j.techfore.2022.122026

[26] Bahrami M, Shokouhyar S. The role of big data analytics capabilities in bolstering supply chain resilience and firm performance: A dynamic capability view. *Information Technology & People*. 2022;35:1621–1651. https://doi.org/10.1108/ITP-01-2021-0048

[27] Belhadi A, Kamble S, Jabbour CJC, Gunasekaran A, Ndubisi NO, Venkatesh M. Manufacturing and service supply chain resilience to the COVID-19 outbreak: Lessons learned from the automobile and airline industries. *Technological Forecasting and Social Change*. 2021;163:120447. https://doi.org/10.1016/j.techfore.2020.120447

[28] Ivanov D. Digital supply chain management and technology to enhance resilience by building and using end-to-end visibility during the COVID-19 pandemic. *IEEE Transactions on Engineering Management*. 2024;71:10485–10495. https://doi.org/10.1109/TEM.2021.3095193

[29] Spieske A, Gebhardt M, Kopyto M, Birkel H, Hartmann E. The future of Industry 4.0 and supply chain resilience after the COVID-19 pandemic: Empirical evidence from a Delphi study. *Computers & Industrial Engineering*. 2023;181:109344. https://doi.org/10.1016/j.cie.2023.109344

[30] Shahzadi G, Jia F, Chen L, John A. AI adoption in supply chain management: A systematic literature review. *Journal of Manufacturing Technology Management*. 2024;35:1125–1150. https://doi.org/10.1108/JMTM-09-2023-0431