Strategic Procurement and Long-Lead Electrical Equipment Management for Efficient Delivery of Saudi Arabia's Regional Infrastructure Projects

Abstract

Regional infrastructure programmes in Saudi Arabia are predicated on electrical assets and the requirements for their specification, manufacture, inspection and commissioning frequently go well beyond the normal course of a construction procurement. A transformer arriving late can in effect delay energisation even if the civil works are well advanced. On the flip side equipment can arrive prior to design and site readiness thereby creating storage exposure and working capital costs. This paper presents a critical review of how strategic procurement can be used to manage the interdependencies across the project lifecycle. It draws on 30 peer-reviewed papers from 2020 to 2025 which are assessed via a structured, mechanism-based comparison of construction supply chains, project delays in the Saudi context, EPC integration, digital logistics and resilience. The review shows that procurement performance is a function of early technical definition, supplier capability, commercial governance, manufacturing visibility and installation readiness. A five gate, interface based management framework is developed which links engineering freeze, sourcing commitment, fabrication assurance, delivery control and energisation acceptance. Risk weighted buffers, dual path contingency planning and a measurable control dashboard are proposed which are all appropriate for use in the context of geographically dispersed infrastructure packages. The propositions are purely analytical in nature and not empirically tested; their value is in the specification of testable relationships and the delineation of decision rights. The paper makes a contribution in the form of an equipment based explanation of delay propagation and in the form of a practical research agenda for improving project delivery in the region under Saudi Vision 2030.

Keywords: strategic procurement; long-lead equipment; transformers; switchgear; EPC; infrastructure; supply-chain resilience; Saudi Arabia

1. Introduction

Electrical infrastructure delivery is usually measured in terms of construction progress, but the real bottleneck may well be outside the project boundary. The high voltage transformers, medium voltage switchgear, protection and control panels, industrial drives, substation automation equipment and specialist cables will all have a requirement for detailed engineering approval, be subject to limited factory capacity, require type testing and will have a requirement for sequence

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of delivery. They can't be treated as a simple late stage procurement. If the electrical package is behind, the mechanical completion of the associated buildings, pumping stations or transport facilities doesn't necessarily mean that the package is going to be operational. The actual performance outcome is therefore reliable energisation and handover rather than simply the placing of purchase orders.

This is particularly pertinent to the regional programmes in Saudi Arabia where the various utilities, transport links, water assets and public service facilities have to be in step across a number of sites which are geographically dispersed. Evidence from the Saudi construction sector points to delayed equipment delivery, delayed design approvals, delayed payments and poor coordination as the key drivers of schedule variation [2,10-12]. A survey of pipeline construction (not an electrical project per se) does provide some useful evidence as to why material interfaces are so important: problems with delivery can stem from upstream approvals and owner supplied inputs as much as from the transport issue itself [2]. One has to be cautious about generalising but the underlying cause is certainly relevant to electrical packages which are subject to a sequence of acceptance milestones.

Research into EPC supply chain integration connects procurement outcomes to cross organisational information sharing, contract management and operational co-ordination [3,16]. Construction supply chain reviews have also identified the continuing fragmentation between the designer, the buyer, the manufacturer and the installer [4-6]. The bulk of the work in this area tends to be at the level of aggregated project materials or generic integration capability and provides very little in the way of specific guidance for products with engineered configurations, production slots, witnessed factory acceptance tests and commissioning dependencies. An electrical procurement strategy has to be aware of the difference between the supplier's quoted delivery date and the date on which an approved and operable asset can in fact be installed and switched on.

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The paper is aimed at developing a defensible strategic procurement model for long-lead electrical assets in support of Saudi regional infrastructure. The analysis is driven by four objectives: to identify the mechanisms by which engineering and commercial decisions impact delivery reliability; to assess the organisational and digital controls that enable factory to site progress to be visible; to incorporate supply risk with construction readiness and lifecycle value; and to produce a staged framework which can be used with tangible performance measures. The core proposition is that managing a long-lead item is about managing an interdependent technical and contractual pathway rather than simply getting the item to site.

2. Review Design and Analytical Approach

We took a structured critical narrative review approach as the research question covers a range of evidence using very different methodologies and outcome definitions. The time frame was restricted to 2020–2025 and the sources were selected on the basis of their substantive relevance to construction procurement, EPC integration, Saudi construction delays, logistics digitalisation, sourcing resilience and interface governance. The three studies provided were used as the anchor texts: fast track coordination in a Gulf context [1], procurement integration in international EPC projects [3] and the empirically ranked delivery delays in the Saudi pipeline project [2]. Further publications were identified via the publisher, institutional or DOI linked bibliographic records. The resulting purposive corpus comprises thirty publications and it is not claimed to be a statistically representative or exhaustive database sample.

Each source was assessed against five analytic fields: project setting and unit of analysis; the delay mechanism(s) that were either demonstrated or proposed; the procurement decision that was in issue; the type of evidence; and the degree of transferability to the domain of engineered electrical assets. Empirical surveys and case studies were treated as context specific observations, the reviews and digital framework papers as providing organisational constructs and potential interventions. There was no pooling of findings into a numerical effect size as the studies differ in terms of population, project definition and the measurement scales employed.

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The synthesis instead employed explanatory comparison and negative case reasoning in order to assess the proposed control under the conditions in which it might lead to cost, rigidity or additional interface work.

There are two methodological limitations to this approach. Firstly, the direct peer-reviewed evidence that isolates transformer and switchgear procurement within the Saudi regional programmes is considerably more limited in scope than the wider body of evidence on construction management that we have drawn upon here. The equipment specific recommendations are therefore in the nature of reasoned applications rather than reported findings. Secondly, access was variable by publisher with some of the analyses being based on published abstracts and bibliographic descriptions rather than the full articles. The argument therefore makes a clear distinction between the observations that are supported and those that are the product of the paper's proposed operational design. Table 1 makes that distinction and explains why the claim of overall procurement integration cannot be taken as evidence of schedule improvement at the equipment level.

Table 1. Evidence appraisal and equipment-specific transfer boundaries (author-developed synthesis).

Evidence domain	What published studies support	Boundary when applying to electrical assets	Analytical implication
Saudi delay research	Approvals, finances, communication and delivery interact [2,10–12,21,22,29].	Sector and respondent heterogeneity limit equipment-specific inference.	Track coupled root causes rather than labeling every variance a vendor fault.
EPC integration	Cross-party information sharing and coordination affect procurement performance [3,16].	Aggregate procurement performance is not the same as energisation readiness.	Use a common package baseline and cross-functional milestones.

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Sourcing and resilience	Portfolio selection and supplier backup reduce selected risks [13,17,20,26].	Alternative equipment may need redesign or qualification.	Pre-qualify technical substitution before relying on dual sourcing.
Digital supply chain	BIM and digital twins can improve information traceability [4,9,14,15,24,25].	Data quality and interoperability constrain practical value.	Require evidence-linked status and human approval at decision gates.

3. The Long-Lead Equipment Problem

Long lead time is typically portrayed as a single period from order to receipt. With configured electrical assets it's a whole lot more complex and the elapsed time will consist of requirement definition, design review, commercial evaluation, manufacturing slot allocation, detailed drawings, purchase of specialist components, fabrication, inspection, release, international or domestic freight and site acceptance. A number of the activities can run in parallel and a number of them cannot proceed without the prior stage being complete. The real issue is not just how long a stage takes in the normal case but whether the output of that stage is such that the next stage can proceed. A purchase order can be issued with unresolved relay requirements or busbar interfaces and that may give the impression of progress whilst in reality manufacturing readiness is not achieved.

The construction literature is supportive of an interface interpretation. Gulf fast track research has demonstrated that overlap between design, procurement and construction can lead to a reduction in nominal duration but at the same time can result in a significant increase in rework, design change and contract risk if the decisions are still immature [1]. The literature on construction supply chain management identifies relationship quality, information integration and logistical coordination as being as important as the purchasing aspect [5,6]. For electrical equipment the engineering gate therefore needs to be able to make the distinction between information which is stable enough to allow reservation of factory capacity and information

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which is stable enough to allow for irreversible fabrication. This enables you to accelerate responsibly without treating early technical commitment as being equivalent to efficiency.

A second characteristic is path dependency. The impact of a late transformer is dictated by cable termination, protection settings, access, the various permits for energisation, utility witness testing and load acceptance. A relatively minor change to the earthing or metering arrangement can in turn trigger a cascade of changes across the vendor documentation, the consultant documentation and the inspection plans. The Saudi evidence of miscommunication and slow approvals further supports the need for formally managed interfaces [11,22,29]. The risk unit in this scenario becomes the entire energisation chain (including owner decisions and contractor readiness) rather than a single supplier performance metric.

A third characteristic is scarcity under variable demand. Custom ratings, high short circuit withstand, software compatibility and specialist certification can all serve to restrict the pool of potential suppliers. Diversification isn't always an option if a redesign or utility acceptance is going to be required. Backup sourcing may be of some benefit in certain construction networks [13] but a nominal alternative that doesn't have the requisite approved technical equivalence provides very little resilience. Procurement teams should pre-qualify viable alternatives before any disruption occurs and should quantify the engineering lead time for substitution (including drawing revision and type test evidence). This creates an option that can be exercised rather than just a name on a supplier list.

4. Strategic Sourcing and Contract Formation

Strategic sourcing starts with package segmentation. Routine consumables can be managed via local inventory policies; engineered equipment will require more considered decisions based on criticality, market capacity, substitutability and the exposure of the downstream works. Pacheco and Clausen [20] show the value of looking at supply risk, commercial impact and sustainability

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in a combined fashion rather than just on purchase value. For regional infrastructure the segmentation criteria should include energisation criticality, contractual float, configuration uniqueness, installed base compatibility, warranty service availability and the cost of interruption. All of these factors can in principle justify early engagement even if the item in question is only a small part of the overall contract value.

Tender evaluation should go beyond the initial price to the credibility of the delivery commitments. The technical compliance matrix, the manufacturing load declaration, the subcontractor dependency map, the factory test capacity, the local servicing arrangements and the evidence of previous schedule performance are all far more informative than a vague promise of quick dispatch. BIM enabled procurement research can support a multicriteria evaluation incorporating cost, schedule, sustainability, quality and relationship [30]. The weighting of the criteria must be explicit though. A low bid is not necessarily the economically preferred option if its failure would result in a delay to a substation which in turn controls a number of downstream packages. The comparison must state which of the reliability assumptions are actually verified and which are purely subjective.

Contract design can either pass on unmanageable risk or establish workable joint controls. The milestones should cover the release of approved drawings, long lead component release, manufacture completion, factory acceptance, shipping readiness, site delivery and commissioning support. The notice requirements should be such that late owner information and supplier non-performance are easily identifiable. The change mechanisms should provide for both the cost of the direct change and the cost of consequential loss of manufacturing slots. Fixed liquidated damages do not in any way substitute for the normal level of operational transparency and the aggressive transfer of design risk which is uncertain may simply lead to higher contingency pricing. Regional research into delayed payments suggests that commercial liquidity is also an area which should be monitored as the cash constraints of both supplier and contractor can have a knock-on effect through the production schedule [10,12].

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Framework agreements across regional projects can in fact aggregate demand and secure capacity, but they come with governance costs. Standardised equipment families will enable common spares and common quality plans. Poorly governed bundling can in effect lock a programme into a single supplier or into a set of obsolete specifications. The right portfolio principle is conditional standardisation: standardise where appropriate (interfaces and performance), preserve project specific safety and network constraints and maintain competitive options at the planned decision points. There is a body of work on sustainable procurement and supply chain resilience which suggests that procurement portfolios should be viewed as evolving systems rather than as one-off award decisions [17,20,26].

An equipment level business case should also look at the full cost of acceleration. Premium freight may well get you a few days but may be of no benefit if the installation permits are still outstanding. The cost of reserving a second factory slot has option value only if the drawings and the contract allow for reassignment. Expediting a panel prior to interface tests being agreed may well create defects which then eat into your commissioning float. The economic evaluation should therefore compare the cost of the intervention with the probability weighted value of earlier service availability, taking into account downstream bottlenecks and the reversibility of the decision. That will ensure that the obvious purchase order milestone doesn't in fact dominate the much less visible operational outcome.

5. Integration of Engineering, Manufacturing and Site Readiness

The key release decision is prior to manufacture. A controlled technical baseline should cover electrical ratings, applicable utility standards, short circuit assumptions, protection philosophy, comms protocols, physical dimensions, interfaces, installation environment and key accessories. The status of this baseline must be visible to the supplier, designer, programme scheduler and commissioning lead. An engineering freeze record does not mean that changes are off the table; it simply establishes the cost and schedule impact of any changes. Egbelakin et al [1] describe the cost of unmanaged overlap in accelerated delivery and Huang and Li [3] point to the

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importance of coordinated stakeholder processes in achieving successful EPC procurement. Together these point to the need for document control to become a contractual decision mechanism.

Factory oversight must be measuring actual executable progress rather than just the self-reported % complete. The normal checkpoints would be purchase order confirmation for components, receipt of electrical steel or other key inputs where applicable, core and enclosure fabrication, assembly, wiring, routine testing, corrective actions and release documentation. An ITP would specify the hold points, the witness responsibilities, the test record format and the time allowed to resolve any deviation. Remote evidence can be of use but should not be taken as a substitute for the inspections required by contract or regulator. The progress reported is only as good as the link to dated physical outputs and quality acceptance rather than just some general schedule description.

Delivery plans are also very much dictated by the readiness of the receiving project. A manufacturer can be on schedule with its contractual delivery date and yet the equipment can still be stranded as the foundations, access, lifting arrangements, environmental protection or the customs docs are not complete. There's a well established body of construction logistics literature which shows the operational advantages of aligning material status to site plans and delivery sequences [8,24,25]. For electrical programmes a readiness certificate should incorporate civil completion, crane and access plan, storage conditions, interface drawings, local permits, inspection resources and energisation windows. The best delivery commitment is one that is fully co-ordinated between factory and site and which is reviewed each time either party makes a change.

Ultimately acceptance has to go beyond just the physical receipt of the item. Switchgear and control panels will need settings checks, interface tests and documented software configurations. The transformers will need installation checks, protection coordination and commissioning records. Some of these activities will be project specific and will be governed by the utility. A

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procurement dashboard which simply flags items as complete at goods receipt will therefore be a significant underestimation of the residual risk. The final stage is to track against the agreed handover definition the outstanding documentation, defects, spares, training, warranties and connection permissions. It is only at this point that procurement performance actually becomes meaningful to the end users of the infrastructure.

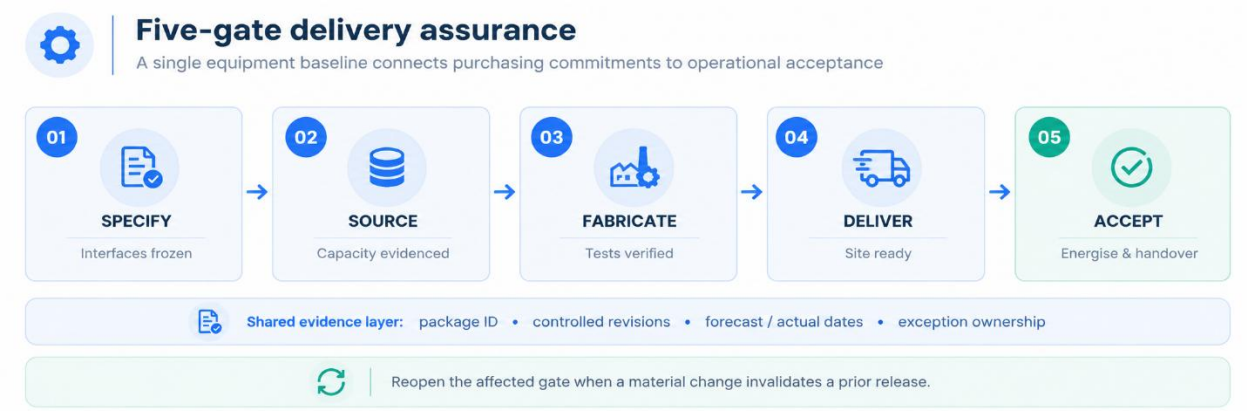


Figure 1. Equipment-centred procurement and delivery control gates (original conceptual illustration).

6. Risk Propagation, Scheduling and Contingency

An engineered asset may be late because a supplier have missed their manufacturing commitment, but the root cause analysis has to look at the decisions upstream. The Saudi pipeline study by Alshibani and co-workers [2] identifies equipment delivery and drawing approvals as among the key delay drivers and its focus on root cause would certainly not be content with just identifying the symptom. The wider Saudi reviews and regional surveys are equally clear in their findings with a combination of poor planning, slow decision making and lack of resources cited as the principal causes [10,11,21,22]. A causal model therefore needs to establish the link between the event, the affected interface, the lost float, the knock on work and the recovery option. Simply having 'supplier delay' in your risk register is not going to get you to the root of the problem.

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Risk registers should separate probability from consequence and from timing. A fault of moderate probability in a protection cabinet may have a greater impact on the programme than a more frequent occurrence of a shortage of routine materials (the latter of course being a much more common event) if the former actually prevents energisation. Two time horizons are relevant: the latest responsible decision date for technical release and the latest recoverable delivery date prior to contractual completion being exposed. The monitoring should be on the gap between these two dates and the credible remaining lead time. The scheduling model should calculate the sensitivity of the energisation milestones to individual packages rather than simply assume that any delay in a shipment is a critical one.

Contingency plans should be in place prior to any disruption. The options are: reserved manufacturing capacity, tested alternative components, phased energisation, approved temporary facilities, planned overtime for installation and strategically located spares. Each option has its own set of activation criteria and cost. Backup suppliers have been incorporated as a resilience mechanism in the construction network [13], but their value is predicated on interoperability and qualification for the type of electrical equipment in question. Replacing a transformer with a non-identical model is likely to result in changes to protection grading, civil clearances and maintenance. The plan therefore needs to be focused on recoverability following technical verification rather than on the number of backup suppliers.

Buffers too need discrimination. Scheduling contingency around engineering approvals may be more worthwhile than blanket stockholding, especially with equipment which is sensitive to humidity, damage or obsolescence. For projects spread across the globe, selective regional consolidation can reduce the number of times the equipment has to be transported but may in turn lead to double handling and double insurance. Critical chain assumptions need to be tuned to the actual vendor performance and the actual access constraints of the project. There is some interesting work from Saudi Arabia on machine learning for delay prediction which suggests the potential for data driven early warning systems [23]. The caveat of course is that the model

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results cannot be taken as being applicable to a small sample of very different electrical packages. Decision support is most defensible when the uncertainty ranges and the quality of the data are all visible.

To operationalise the new responsible decision date you reverse map the intended energisation milestone back through commissioning, installation, delivery, factory acceptance, fabrication and engineering release. Each duration should be a range (backed up by programme history or written supplier evidence) not a single unqualified estimate. The resultant decision calendar is the basis on which everyone else can escalate. If an overdue protection study is such as to impact the final recoverable manufacturing date then the remedy is an engineering decision; a number of supplier reminders will not get you the time back. That distinction is important in terms of who actually has control of the critical constraint.



Figure 2. Plausible delay propagation and control points; not an empirical estimate (original conceptual illustration).

7. Digital Visibility and Decision Governance

Digital procurement is only of value if it changes the way decisions are made. Reviews of the digitalisation of construction identify BIM, connected asset records, distributed ledgers and

supply chain analytics as potential means of improving visibility and traceability [4,14,15]. Digital twin studies likewise link the physical movement of materials to design and logistics data [9,24–27]. For long lead electrical equipment the minimum viable architecture is typically going to be simpler than a fully autonomous platform. The simplest architecture is a shared package identifier which links the technical baseline, purchase order, supplier schedule, inspection evidence, location and receiving site readiness. A controlled interface log will then specify who owns each overdue action and what impact it has on the critical path.

A common data environment can bring together the various dates which would otherwise be held separately. The supplier will have a factory completion date, logistics will have a vessel arrival date and the site will have their own installation readiness date. Without a common event definition each of the organisations can report that they're on track even as the overall completion date goes backwards. A good event model will separate forecast from actual dates, will attach the evidence, will capture the reason codes for any variance and will record the decisions that change the approved baseline. The transparency should extend to escalation thresholds as well. A slipped drawing approval becomes a management exception when it impacts on the manufacturing release date (not just after the shipping date has been missed).

Digital integration also opens up new avenues for vulnerability. Vendor platforms may have totally incompatible data structures. Protection data, engineering drawings and manufacturing records are all potentially commercially sensitive. An automated forecast may be based on outdated assumptions which it then propagates. A data governance protocol should therefore specify update frequency, who is responsible for validation, who can access the records and how long they are to be retained. The emerging body of literature on the logistics twin is very much focused on the potential for integration but there are still quite a few unanswered questions around the actual implementation and field validation [9,25]. You can't just go in and adopt the technology without rethinking the way accountability works as that will lead to the rapid dissemination of unreliable information. The framework we're proposing here sees digital tools as evidence channels within a human governed milestone rather than as a replacement for engineering judgement.

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The model also assumes that contractual data can be shared without breach of supplier confidentiality. In practice the model may well use a tiered approach to visibility: programme teams would see milestone status and exception codes; specialist engineers would have access to the protected configuration files; commercial people would be able to see the manufacturing commitments and payments; and auditors would have a controlled record of the approvals. Access would be by role and any interface changes would have to preserve the revision history. This would make it much easier to work out where a missed delivery had come from (design, manufacture, transport or project readiness) without necessarily having to circulate the actual proprietary technical data.

8. Implications for Saudi Regional Infrastructure

Regional infrastructure has another coordination issue in that the projects may be quite distant from each other in terms of transport route, may be with different contractors, may have very different site access situations and may be sequenced around different electricity/utility connection windows. The value of early order placement is therefore very much project specific. A procurement package may be very close to the factory in terms of geography but operationally very far from acceptance if the permits and the downstream interfaces aren't sorted. On the other hand you can have a very remote project with very stable requirements and very well co-ordinated commissioning which is going to be a lot more predictable. The appropriate analytical unit is therefore the regional asset service chain (source, transport, installation and energisation).

Saudi evidence would suggest that it would be premature to point the finger at any one particular party as the cause of the delays. The reviews of the Saudi construction sector point to a number of factors including approvals, planning, communication, finance and material availability [10,11,21,29]. A study in the Makkah region similarly identifies the importance of subcontractor

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coordination and project management capability [22]. These are findings from different sectors and different samples and so support the governance controls proposed here, but do not in any way establish the incidence of electrical equipment failure. Any regional implementation would be best underpinned by a baseline study of actual order to energisation records, broken down by voltage class, equipment family, employer, contract type and location.

Alignment with Saudi Vision 2030 should be in operational rather than promotional terms. Reliable commissioning will underpin the availability of electricity, water, mobility and industrial services. Greater transparency in procurement can reduce the amount of idle construction capacity and the need for emergency logistics. A consistent equipment family can improve maintainability and skills transfer. Local supplier development can enhance responsiveness but this will only be the case if it includes engineering capability, certification, testing and after sales support. It should not be equated automatically with reduced lead time or lower risk. Public and private owners should be measuring the actual lifecycle benefits and not just assume that localisation, digitisation and standardisation will deliver.

Finally regional portfolios provide the ideal environment for learning across projects. A common taxonomy of equipment classes, approval times, supplier constraints and energisation dependencies would enable meaningful comparison without obliterating the site specificities. Procurement leaders could determine whether a particular recurring bottleneck was due to one factory, one design, a number of late customer decisions or a fundamental mismatch between the delivery and installation plans. That insight would be of value in shaping future tender requirements and in setting realistic allowances rather than simply providing a post-mortem scorecard. For learning to be reliable you also need to record the cost of successful recoveries and the cost of precautions as well as the cost of the completed delay.

9. An Integrated Five-Gate Framework

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The synthesis results in five decision gates. Gate 1 (specification readiness) requires a controlled equipment schedule, approved functional requirements and interface ownership. Gate 2 (sourcing commitment) requires a defensible bid assessment, capacity evidence, agreed change procedure and a credible manufacturing/release plan. Gate 3 (fabrication assurance) monitors physical production and quality hold points against the verified records. Gate 4 (delivery integration) brings together the shipment forecast with the receiving site readiness and logistics constraints. Gate 5 (operational acceptance) is the gate which closes out the tests, the documentation, the residual defects and the energisation permits. There must be a named accountable owner for each gate and they must be able to re-open a gate if a material change invalidates the assumptions that were made.

The gates work as a single system rather than a series of discrete waterfalls. Market engagement and manufacturing reservations can start in the early engineering phase with clearly defined reversible commitments. Site works can go ahead during fabrication as long as design changes are properly controlled and the contractual responsibilities are clear. The decision rules need to make the overlap explicit. You only release a limited activity when the expected schedule benefit is greater than the likely cost of rework and when the consequence of failure is recoverable. That's the logic that deals with the tension between the benefits of fast tracking and the dangers of premature commitment as evidenced in the Gulf construction case [1].

A performance dashboard should be reporting far more than just procurement cycle time. It should be reporting on design approval age, factory slot confidence, the % of milestones with evidence, forecast energisation variance, site readiness alignment, quality non-conformance closure and the cost of preventative interventions. Table 2 sets out the owners, triggers and responses for these. The frequency of review can be increased as an item approaches a non-recoverable decision date and high uncertainty packages will require a far more active exception management regime than a stable catalogue purchase. Cross project oversight can then be used to identify common bottlenecks and negotiate portfolio level relief without at the same time obscuring the local project risk.

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The framework is explicitly falsifiable. It should be evaluated against similar projects using schedule reliability, total installed cost, change order intensity and commissioning delay as the outcome measures. A plausible mechanism is that greater technical clarity upfront leads to less manufacturing disruption, verified supplier visibility leads to shorter escalation times and synchronised site readiness leads to less idle inventory. An alternative hypothesis is that more gates and more reporting simply increases transaction costs without any impact on the reliability of completion. The prospective assessment should test both of these hypotheses and should not use a simple self reported satisfaction score as a stand in for actual delivery performance.

Table 2. Proposed risk-based control dashboard with functional accountability (author-developed).

Control measure	Accountable function	Exception signal	Required decision or response
Engineering approval age	Lead electrical engineer	Document overdue beyond latest release date	Resolve technical interface; quantify schedule impact.
Factory-slot confidence	Procurement manager	Capacity evidence missing or revised	Escalate manufacturer; assess qualified alternatives.
Verified fabrication progress	Supplier quality lead	Milestone reported without test or physical evidence	Reforecast completion and inspect constraint.
Logistics-to-site alignment	Construction manager	Confirmed arrival precedes safe receiving readiness	Coordinate delivery, protected storage or phased release.
Energisation forecast variance	Programme controls lead	Forecast exceeds approved operational milestone	Run recovery scenarios and approve intervention.

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Defect and dossier closure	Commissioning manager	Open critical punch items or missing test records	Hold acceptance until compliant documentation is complete.

10. Discussion, Limitations and Research Directions

The review extends the construction supply chain integration literature by situating procurement performance at the nexus of technical maturity, commercial viability and operational acceptability. General EPC work has tended to focus on the importance of stakeholder collaboration [3,16], whilst resilience work has stressed the importance of adaptive sourcing and network capacity [5,13,18,26]. The electrical equipment context provides an important caveat in that alternative capacity is of no use unless the design, the tests and the utility requirements all allow for substitution. Supply chain resilience is therefore in part an engineering property of the asset architecture rather than simply a purchasing issue. The same applies to digital coordination; a complete tracking record is not in itself a technically acceptable item.

A second point is about causality. The propensity to see late receipt as a supplier failure can mask a number of weak owner decisions, late drawing approval, finance issues and access constraints. There is survey evidence from the Saudi projects which is consistent with a multi-actor explanation [2,10,12,29] but the causal inference is very limited as most of the work to date has been based on retrospective judgement rather than on timestamped event records. Future work should be to build up package level data which links the document revisions, purchase order dates, manufacturing inspection dates, payment milestones, site readiness certificates and the first successful energisation. This would allow you to look at the propagation of delay across equipment families and project delivery models.

The control model proposed also involves a number of trade-offs. Buying early may secure your scarce production slots at the expense of being exposed to specification changes; single sourcing

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to achieve standardisation may improve compatibility but will concentrate the disruption risk; comprehensive digital reporting may improve transparency but will be a burden on the small supplier. The sustainability dimension adds another layer of complexity as the environmental impact of repeated freight, rework, premature replacement and inefficient storage is as much a consideration as the commercial impact [17,20]. Future work would be to assess marginal value i.e. which additional inspection, which additional buffer, which additional digital feature or which additional sourcing option delivers a measurable benefit relative to its cost. The most promising empirical design would be a multi-project longitudinal study with pre-defined indicators, implementation fidelity checks and sensitivity analysis.

The review is constrained by the selective nature of the literature it has drawn upon, the extent to which it has attempted to cross-sector and the lack of any independent programme records. It is not claimed that the 30 publications represent all the relevant work or that the 5 gates have been field validated. Market conditions, utility standards and regulatory regimes are all subject to change over time so package specific due diligence is absolutely essential. The propositions put forward are however sufficiently specific to enable field testing: distinguish between nominal and executable lead times; tie manufacturing commitments to stable technical interfaces; link delivery dates to installation readiness; and assess procurement success at the point of operational acceptance rather than at dispatch.

Implementation should be staged in accordance with supplier maturity and contract size. Tezel et al [7] highlight that blockchain readiness is a matter of governance across the construction supply chain and Onyia et al [19] point to a number of adoption barriers which are not simply down to the availability of the software. For infrastructure programmes a shared spreadsheet with timestamps may be preferable to a platform if the suppliers are not able to provide reliable data feeds. The same is true of the review evidence on offsite supply chains [28] which suggests that production visibility is only of value if transport and downstream assembly are coordinated. The managerial question is therefore not whether the data element increases the detail on the dashboard but whether it enables a timely action. Implementation pilots should assess the completeness of equipment registers, the latency between factory events and escalation, the

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accuracy of readiness forecasts and the outcomes. It is vital to record the instances of missing data and cancelled interventions as success only observations will inflate the apparent benefits. Baseline measurements should be taken prior to the deployment of the software so that the project team can separate out the gains from the technology from those which may be due to changes in staffing, supplier mix or workload.

11. Conclusion

Long lead electrical equipment should be treated as a programme critical system of approvals, manufacturing decisions, logistics dependencies and commissioning interfaces. There is clear evidence from Saudi and international sources that late materials, poor coordination, commercial pressures and uncontrolled change can all combine to have a negative effect on schedule reliability [1–3,10–12]. The paper proposes an integrated five gate approach which places technical definition before any irreversible commitment, requires evidence of factory progress, ensures site and shipping readiness are aligned and defines successful completion as energisation and handover. The relevance to the Saudi region is that it provides a way of making the full procurement to service pathway visible across the various projects. The next step is to test the approach empirically using real equipment records and transparent counterfactuals. In the absence of that evidence the approach provides a structured and contestable set of management guidelines rather than a proven methodology for delivering against schedule.

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