SUPPLY CHAIN MANAGEMENT

Lean Third-Party Logistics Management for Saudi Healthcare Distribution: Reducing Warehouse Waste, Operating Costs and Supply Chain Inefficiencies under Vision 2030

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Published November 2026

Abstract

Saudi healthcare distribution must reconcile operational economy with uninterrupted access to clinically essential products. This critical integrative review examines how lean third-party logistics can reduce warehouse waste, fulfilment costs and process variability without undermining product integrity, stock availability or resilience. A focused, transparent appraisal of thirty DOI-traceable publications from 2020–2025 considers pharmaceutical supply chains, order picking, inventory control, digital warehousing, cold-chain monitoring and sustainability. Evidence supports value-stream mapping, differentiated stock policies, standardised work and data-enabled exception management as mutually reinforcing practices, but does not establish a universal financial return. The proposed framework combines service criticality, total cost, cold-chain assurance and electrical infrastructure reliability within contractual governance. Saudi-specific evidence highlights shortage exposure and inventory waste, while much technological evidence remains transferable rather than locally validated. The paper develops a practical scorecard, phased implementation logic and research agenda for controlled evaluation. The central conclusion is that lean healthcare logistics should remove avoidable process waste while deliberately retaining clinically justified protective capacity. Such calibrated efficiency supports Vision 2030 through safer distribution, more productive logistics assets and stronger infrastructure resilience.

Keywords: lean third-party logistics; Saudi healthcare distribution; warehouse waste; pharmaceutical supply chain; cold-chain integrity; Vision 2030; electrical resilience

1 Introduction

Healthcare distribution is not an ordinary warehouse service. Delayed consumables interrupt procedures; poorly controlled medicines may become unusable; and the cheapest delivery plan can impose expensive consequences on a hospital. Third-party logistics providers (3PLs) therefore occupy an unusual position between national procurement structures, manufacturers, distributors, hospitals and patients. They must pursue predictable service and economical handling while meeting strict requirements for identity, traceability, temperature, security and timely replenishment. Saudi Arabia's Vision 2030 makes this balancing problem strategically relevant because health-service transformation and the development of efficient national logistics capacity are progressing together. Lean management offers a process-centred response, yet uncritical elimination of every apparent buffer could produce shortages rather than value.

Recent pharmaceutical reviews identify lean opportunities in receiving, put-away, storage, picking and dispatch, while documenting evidence gaps around implementation and quality compliance [1]. A warehouse value-stream case study shows how process observation exposes non-value-adding

waiting and hand-offs [2]. Saudi studies, however, reveal problems beyond local picking productivity: essential-medicine shortages are linked to interconnected planning and supply difficulties [3, 4], whereas a tertiary-hospital inventory assessment reports financially measurable expired and inactive stock [5]. These findings suggest a dual imperative: protect the flow of clinically needed goods and remove holdings or activities that do not contribute to that purpose. Labour productivity alone cannot represent success.

This paper advances a critical, Saudi-oriented framework rather than reporting an original experiment. It asks which types of waste are reducible, which protective resources are clinically warranted and how contract design can prevent cost displacement between 3PLs and health facilities. The analysis also connects the physical warehouse to its electrical foundation. Refrigeration, environmental sensors, scanning networks, automation and dispatch charging require dependable power, and their failure can rapidly erase savings from process improvements. The manuscript consequently treats infrastructure reliability as a safety and total-cost constraint, not as an unrelated energy narrative.

The national context also changes the meaning of distribution productivity. Large metropolitan hospitals may support frequent consolidated drops, whereas remote facilities face longer replenishment lead times and fewer alternative carriers. A single uniform service policy would conceal these geographical differences. Saudi procurement centralisation may create purchasing leverage, but it also increases the value of accurate downstream demand signals, clear accountability and coordinated inventory release. The role of 3PL management is therefore to connect procurement efficiency with point-of-care dependability. This implies mapping not only physical pallets but also authorisation messages, invoice disputes, catalogue changes and exception decisions. When data are unreliable, an apparently lean stock target becomes operationally fragile. A service-class matrix should precede any target for inventory reduction.

2 Aims, objectives and research questions

The aim is to formulate an evidence-informed approach for reducing waste and operating costs in Saudi healthcare 3PL networks while maintaining assured availability, product quality and resilient service. Four objectives guide the review: identify the principal sources of warehouse and interface waste; critically compare lean, inventory and digital interventions; specify integrated operational, financial, clinical and electrical measures; and establish implementation and research priorities relevant to Vision 2030. The linked research questions concern where waste arises, which trade-offs constrain improvement, how data and infrastructure affect outcomes, and what evidence would establish local effectiveness. A framework is warranted because isolated interventions frequently optimise one activity while transferring effort, risk or cost elsewhere.

3 Review methodology and evidence appraisal

A focused critical integrative approach was adopted to combine heterogeneous evidence rather than claim an exhaustive systematic review or a quantitative meta-analysis. Searches and source checks used publisher pages, scholarly indexing records and accessible bibliographic information, with combinations of pharmaceutical supply chain, healthcare logistics, lean warehousing, value-stream mapping, order picking, inventory waste, cold-chain monitoring, warehouse digitalisation, resilience and green operations. Eligible material was confined to research published online or in print during 2020–2025, with a discoverable DOI, clear methodological description and material relevance to at

least one review question. The thirty selected references were screened for title, topic, year and DOI correspondence using accessible records. This was purposive sampling of pertinent literature, not a reproducible claim about the number of records screened in licensed databases.

The evidence was grouped into five analytical streams: Saudi pharmaceutical availability and inventory outcomes; lean pharmaceutical and healthcare practice; warehouse design and order-picking science; cold-chain and network optimisation; and information-enabled sustainability. Studies were appraised for setting, design, observable outcome, transferability and potential bias. Direct Saudi operational evidence received greater contextual weight than generic technology reviews, whereas controlled or empirical evaluations were distinguished from conceptual frameworks, optimisation models and conference demonstrations. Evidence from non-Saudi warehouses informed mechanisms but could not establish Saudi effect sizes. Findings were synthesised narratively across workflow, economics, safety and infrastructure, with conflicting implications retained rather than averaged.

Three methodological safeguards shape the interpretation. First, simulation outputs and modelled optima are not reported as realised savings. Second, different operational denominators are kept separate: cost per order, cost per line, waste value, perfect-order rate and stock-out exposure cannot be interchanged. Third, a reported association between technology and performance is not treated as causal proof. Because no primary interviews, transaction records, temperature logs or facility energy data were collected, the proposed figures and performance architecture are analytical designs rather than empirical observations. The same distinction applies to the illustrative implementation sequence and thresholds, which require local validation.

Interpretive confidence was recorded qualitatively rather than converted into arbitrary numerical weights. Direct observational evidence was considered stronger for claims about a specific process than a purely conceptual proposition; however, a well-defined simulation could still clarify feasible trade-offs. Evidence quality was judged separately from contextual similarity. Thus, a mathematically rigorous European delivery model may be relevant to routing logic but weak support for Saudi labour or electricity cost estimates. Conversely, a descriptive Saudi survey can substantiate perceived shortage drivers without identifying a causal effect. This approach prevents the synthesis from inflating either statistical certainty or local generalisability. The resulting recommendations are framed as conditional decisions to be tested, not established national standards.

4 Theoretical foundation: lean flow under clinical constraints

Lean thinking defines waste relative to value delivered to a specified customer. In healthcare logistics, the customer cannot be represented solely by the purchaser or warehouse supervisor: the receiving clinical service and, ultimately, patient safety also determine value. Conventional waste categories remain useful: excess transport, inventory, motion, waiting, overprocessing, overproduction, defects and underused knowledge. Yet products that appear slow-moving may serve rare emergencies; duplicate verification may be a necessary regulatory control; and additional validated cooling capacity may avert a costly temperature excursion. A defensible lean classification must therefore distinguish avoidable duplication from purposefully retained assurance.

The literature on pharmaceutical supply-chain transformation identifies process integration, standardisation and continuous improvement as relevant but difficult to coordinate across organisations [1]. A further framework proposes alignment of people, methods and supply-chain partners rather than a single technical solution. Research on lean and resilience explicitly cautions that

efficiency improvement must be examined under disruption, not solely during normal throughput [7]. Comparative assessment of lean, agile, resilient and green paradigms reinforces the possibility of complementary capabilities [8], while hospital logistics scholarship argues that routine, route and rhythm need explicit risk and resilience considerations [9]. These insights support a protected-flow principle: eliminate waste only when the change preserves predefined service, quality and recovery requirements.

Two complementary mechanisms explain why 3PL performance may deviate from the narrow warehouse optimum. First, transaction and principal-agent problems arise when the provider is rewarded for throughput, storage utilisation or low unit rates while hospitals bear the consequences of shortages, urgent resupply and clinical interruption. Second, system constraints mean that locally faster picking is worthless when receiving inspection, replenishment authorisation or transport departure remains the bottleneck. Both mechanisms require shared data and joint governance. Contractual service levels should consequently weight clinically vital lines, traceability and temperature compliance alongside expenditure. The appropriate economic objective is the lowest risk-adjusted end-to-end cost, not simply the smallest 3PL invoice.

5 Warehouse waste diagnosis and value-stream redesign

Value-stream mapping should begin with a product-family definition and follow the order from hospital demand signal through allocation, picking, checking, packing, transport and confirmed receipt. Timings must differentiate active process minutes from queue and information delays. In a pharmaceutical warehouse, the map also records quarantine states, batch and expiry identification, cold-room transfers, approvals, returns and deviations. Abideen and Mohamad demonstrate the relevance of value-stream mapping to pharmaceutical warehouse lead-time analysis [2]; practical lean warehouse modelling likewise emphasises perfect-order fulfilment [11]. Neither result should be converted into an assumed Saudi savings percentage, because staffing, product mix and information architecture differ.

Waste commonly accumulates where ownership changes. Inbound pallets wait for document reconciliation; stock is moved between temporary and permanent locations; urgent orders bypass standard waves; repeated manual entry creates discrepancies; and returned material occupies ambiguous status. Such problems can be intensified when manufacturers, 3PLs, procurement platforms and hospital stores maintain inconsistent stock codes. The current-state diagnostic should capture individual timestamps, batch identities, queue causes, touches, kilometres, temperature events and error codes. A future-state design can then replace repeated intervention with verified electronic data, fixed exception pathways and clearly defined release criteria. Figure 1 illustrates this logic without asserting measured improvements.

Several straightforward interventions merit early trials. Five-S workplace organisation and visual controls reduce search and misplaced stock; standardised receiving and packing instructions reduce variation; disciplined cycle counts address record errors; and documented replenishment rules prevent emergency picking from becoming the default. A pharmacy review finds reported benefits from lean and quality-improvement methods but also variation across evaluations [6]. Lean 4.0 literature suggests that digital tools are most useful when they enable a redesigned workflow rather than merely reproduce inefficient paperwork [10]. Every trial should include a pre-agreed balancing measure, such as damaged units or missed critical orders, to detect unintended harm.

A practical observation design should use at least two demand regimes: routine shifts and high-pressure periods such as seasonal surges or urgent hospital requests. For each observation, analysts can record the number of items handled, travel distance, temperature class, departure window, staffing and inventory condition. Normalising time by the complexity of the order helps avoid attributing a slower shift to poorer worker performance when the case mix changed. Pareto charts can then rank recurring delays, while cause-and-effect reviews investigate why they occur. Proposed countermeasures need a clearly owned process, accountable supervisor, training record and audit method. Table 1 translates seven conventional waste categories into healthcare-specific tests and safeguards.

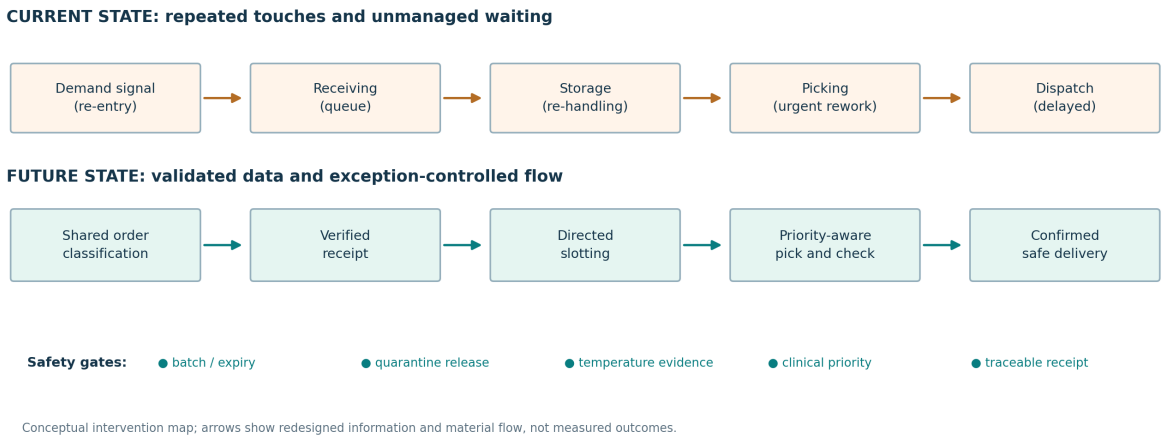


Figure 1. Current-state waste pathways and future-state exception-controlled healthcare 3PL flow (original conceptual schematic; not empirical data)

Table 1. Healthcare warehouse waste, observable signals, proposed interventions and safety constraints

Lean waste	Typical manifestation	Diagnostic indicator	Candidate countermeasure	Clinical safeguard
Waiting	Release queues; order holds	Elapsed time by cause; queue age	Electronic validation; timed escalation	No bypass of quarantine or clinical checks
Motion	Searching and repeated picking walks	Metres per line; ergonomic incidents	Slotting; visual controls; zoning	Controlled, temperature-sensitive items remain secured
Transport	Double handling; unnecessary transfers	Touches per pallet; kilometres per line	Direct put-away; route consolidation	Preserve cold-chain and segregation requirements
Inventory	Expired, idle or duplicated stock	Expiry-adjusted waste; days of cover	ABC–VEN; FEFO; network visibility	Critical-item availability and safety buffers
Defects	Wrong batch, count or destination	Error rate; return causes; traceability	Scan verification; master-data governance	Verified identity and product integrity
Overprocessing	Repeated manual entry and checking	Manual entries per order; exception rate	Interoperable records; risk-based checks	Keep required regulatory verification

Lean waste	Typical manifestation	Diagnostic indicator	Candidate countermeasure	Clinical safeguard
Overproduction	Premature picks; excess packing	Cancelled waves; rework; packaging use	Demand-aligned waves; packaging standards	Urgent service must retain flexibility

6 Inventory segmentation, replenishment and shortage risk

Inventory optimisation is often the largest source of confusion in lean healthcare distribution. Reducing days of cover lowers working capital and storage burden, but service risk is non-linear: one absent emergency product can matter more than numerous excess routine items. ABC analysis classifies financial consumption, whereas VEN classification distinguishes vital, essential and non-essential clinical importance. The Saudi tertiary-hospital assessment of pharmaceutical and non-pharmaceutical waste demonstrates why these dimensions should be combined rather than managed separately [5]. A high-value but non-essential item and a low-value life-saving medicine require different review frequencies, escalation rules and buffers.

Replenishment decisions should incorporate demand variability, supplier lead-time distributions, product shelf life, temperature needs and substitutability. A 3PL may apply first-expiry-first-out allocation where clinically and legally appropriate, prevent expiry through cross-facility visibility and flag orphaned batches before obsolescence. However, first-expiry-first-out does not authorise release of recalled, quarantined or out-of-specification material. Safety stocks should be conditional on clinical class and recovery time, and their calculation should include transport disruption, import dependence and data latency. Shortage research in Saudi Arabia documents local operational causes and perceptions [3, 4]; these findings challenge indiscriminate inventory compression.

The practical question is not how many units can be removed, but which holdings provide no incremental protection. Network pooling may reduce duplicated safety stock if reliable transport and trustworthy visibility permit timely transfers. Conversely, pooling can create a single point of failure when a central depot loses power or access. A resilient design may deliberately retain small regional emergency caches, duplicate validated storage zones or pre-arranged alternative carriers. Differentiated inventory policies can therefore achieve an economic improvement while increasing stock for a narrow subset of vital items. Net value must include expiry reduction, procurement efficiency, emergency freight, clinical stock-outs and the cost of contingency capacity.

Decision makers should distinguish accounting savings from economic benefit. Inventory carrying cost encompasses capital, floor space, refrigeration, insurance and handling, but an inventory release can also raise stock-out probability. A useful objective function therefore combines storage and disposal expenditure, planned freight, emergency replenishment, downtime exposure and the expected consequence of unavailability. Because assigning a monetary price to patient harm is ethically problematic, clinically vital service constraints should be specified before minimising the residual economic objective. Scenario analysis can then test plausible lead-time and demand shocks without inventing probability distributions. Thresholds should be set by clinicians, pharmacy governance, procurement and 3PL operations together, with exception overrides logged for subsequent scrutiny.

7 Picking, slotting, automation and labour

Order picking links layout, stock accuracy, labour effort and delivery reliability. Frequently requested products benefit from accessible locations, while hazardous, controlled or temperature-sensitive items must remain within authorised zones regardless of travel-distance optimisation. Batching can reduce repeated aisle journeys but may delay a critical order; zoning can raise throughput but introduce hand-off errors; and strict wave cut-offs can simplify staffing while undermining clinical responsiveness. Research on combined order-picking decisions, batch optimisation and human-centred planning demonstrates that these choices interact rather than admit a universal best rule [16–18]. Optimisation must therefore consider cut-off deadlines, worker ergonomics, product compatibility and exception priority simultaneously.

Warehouse digitalisation offers visibility and consistency through barcodes, radio-frequency identification, handheld execution, digital twins and robotics. Reviews identify promising benefits in process efficiency and information availability, alongside implementation cost, security, skills and energy challenges [12, 13]. Digital-twin work provides conceptual ways to connect warehouse state and decision rules [14, 15], while algorithmic literature explores hybrid assignment and batching [19]. Automation classifications can help align picking technology with operating conditions [20]. Nevertheless, a robotic system with inaccurate master data merely accelerates wrong transactions. Investments should follow process stabilisation, verified demand analysis and a lifecycle appraisal rather than technological fashion.

Labour design is an equally important control. A good system reduces unnecessary walking and lifting while protecting competency, double-check procedures and fatigue management. Measurement should distinguish productive handling from reasonable safety tasks, and incorporate agency staff training, multilingual instructions, heat exposure at loading docks and night-shift performance. Faster picking may increase downstream checking congestion if resources are not synchronised. The recommended pilot evaluates travel per line, rework, injury signals, order accuracy, departure reliability and employee feedback together. Digital performance dashboards should support coaching and problem solving, not simply rank workers by speed.

A decision support model should treat a delivery as successful only after the correct material has reached an authorised receiving location with intact traceability. Optimisation based purely on distance may bias the planner towards dense, high-volume urban facilities, while a fixed service window can understate the cost of emergency stops. Multi-objective analysis allows warehouse travel, staff workload, critical fill and dispatch lateness to be compared transparently. However, weighting each outcome into one synthetic score can mask unacceptable risks; safety constraints must remain hard limits. The final pilot design should therefore report a vector of separate outcomes, describe the operational circumstances of any trade-off and examine whether gains persist after initial implementation attention diminishes.

8 Cold-chain assurance and electrical infrastructure

Cold-chain distribution demonstrates why a simple time-and-motion analysis is inadequate. Each opening of a cold room, staging delay or vehicle transfer creates potential thermal exposure. Studies investigate both the performance determinants of pharmaceutical cold chains [21] and real-time temperature prediction using physical models [22]. Pharmaceutical delivery optimisation incorporates temperature requirements alongside routing and batching [23], while connected monitoring enables earlier detection of abnormal conditions [24]. These methods improve decision information but do

not replace qualified packaging, calibrated instruments, validated storage ranges or controlled deviation disposition. The metric is not the fewest temperature alarms; it is the fewest genuinely unsafe exposures with complete, reliable records.

The Kingdom's electrical infrastructure is consequently a direct determinant of healthcare 3PL resilience. Cold rooms, compressors, ventilation, battery-supported sensors, network equipment, emergency lighting and automated handling depend on power quality and continuity. Lean layouts can decrease unnecessary door openings, idle conveyors and refrigeration infiltration, but energy reduction must never defeat product storage requirements. Facilities should evaluate sub-metering, compressor efficiency, temperature mapping, maintained uninterruptible supplies for critical controls and properly tested standby generation. Remote depots additionally require contingency for telecommunications interruption and extreme ambient heat. The relevant total cost includes energy consumption, demand peaks, maintenance, backup systems, spoilage exposure and service restoration time.

Electrical resilience should be engineered around failure modes rather than broad claims of being sustainable. A 3PL can document maximum credible power interruption, thermal holdover for each storage zone, sensor autonomy, alarm escalation, generator start reliability and transfer recovery. Temperature records should remain traceable during connectivity outages, with locally buffered events later reconciled into the warehouse system. If fleets are electrified, charging schedules, depot capacity and contingency vehicles need integrated planning to avoid creating dispatch bottlenecks. These engineering controls form a specific connection between modern logistics capacity and Vision 2030: dependable infrastructure permits more efficient service without trading off patient safety. No local energy savings are claimed without metered baselines.

Power resilience should also be specified at the level of evidence. A generator that starts during a scheduled test does not prove that door controls, warehouse software, wireless gateways and monitoring databases will remain coordinated throughout a prolonged outage. Test scenarios should include mains interruption during receiving, sensor communication loss, a refrigeration alarm at night and recovery from a partially completed dispatch transaction. Each scenario needs a named responder, escalation clock, preserved product-status record and criteria for resuming operations. This helps separate merely having backup equipment from demonstrating operational continuity. Investment appraisals should compare tested protection with the maximum credible product-loss and service-disruption exposure, while documenting assumptions instead of presenting unsupported reliability percentages.

9 Transport interfaces, reverse logistics and sustainability

Distribution performance depends on more than warehouse activity. The final order must move through loading, route allocation, vehicle temperature verification, traffic delays, proof of delivery and reconciliation. A network design for pharmaceutical relief demonstrates the value of explicit uncertainty in distribution choices [25]. At ordinary operating scale, scheduled consolidation can reduce fragmented journeys, but excessively infrequent departures increase replenishment latency. Route planning must recognise hospital receiving windows, rural coverage, urgent clinical categories, delivery integrity and backup carrier availability. Third-party carriers need the same batch identification, incident and proof-of-delivery controls as the principal warehouse.

Reverse logistics provides another opportunity to reduce waste through accurate return reason codes, prompt triage and controlled recovery. Packaging can be reused only when validation and

cleanliness permit; medicine returns require product-specific quality rules, full custody evidence and the appropriate disposition authority. Returned temperature-sensitive goods should not be automatically released after visual inspection. Information systems can expose defective processes and environmental gains, yet research warns that environmental performance need not yield immediate financial returns [26]. Digitalisation can support green performance [27] and pharmaceutical supply-chain agility [28], but managers must demonstrate savings after technology, training, electricity, disposal and audit costs.

Environmental objectives should be measured by compatible units: electricity per validated pallet-day, vehicle emissions per delivered order, rejected kilograms by cause and reusable-packaging cycles where permitted. These measures must remain secondary to product integrity and essential service. Wider evidence on green supply chains suggests that performance relationships vary by organisational and contextual conditions [29, 30]. A lean 3PL programme can therefore credibly claim procedural reductions after observation, while any asserted net carbon or financial impact requires a defined baseline and full boundary. A shift that reduces warehouse emissions but transfers refrigerated storage to hospitals is not a system saving.

10 Integrated performance and contractual governance

Figure 2 presents a proposed governance architecture with value, risk and infrastructure constraints surrounding daily improvement. The foundation is a shared master-data dictionary spanning the 3PL, purchasing organisation, hospitals and transport providers. Identifiers should cover item, batch, serial number where relevant, expiry, location, storage class and order priority. Each process event needs a responsible party, a timestamp and an exception state. Contractual dashboards should link order service with inventory condition, traceability, electricity resilience and cost. Table 2 defines practical indicators and balancing measures; these definitions are proposed specifications, not observed Saudi benchmarks.

Payment mechanisms matter because badly framed incentives can create concealed waste. A flat cost-per-line target may encourage unsafe workload compression; payment for occupied pallet locations may reward overstocking; and on-time performance measured only at vehicle departure can hide hospital receipt failures. Contracts should combine verified perfect-order delivery, clinically weighted fill rate, temperature conformity, returns disposition timeliness and transparent total-cost reporting. A risk-sharing provision can allocate responsibilities for forecast error, quality holds, emergency expedites and power events without permitting either party to evade safety obligations. Independent sample audits, joint root-cause reviews and controlled improvement boards should examine the complete patient-facing process.

Implementation is most defensible as a staged series of tests. The first stage establishes process maps, product criticality, data quality, utility reliability and baseline costs. The second uses low-capital pilots in receiving, location discipline and exception coding. The third tests differentiated replenishment and order batching under actual service constraints. The fourth introduces predictive systems or automation only where earlier evidence justifies investment. Every stage requires a predefined time window, matched workload or suitable statistical adjustment, recorded implementation expenditure and explicit stop rules for critical shortages or temperature deviations. After successful testing, standard work and contractual measures can be replicated across facilities with documented local adaptations.

For a trustworthy before-and-after evaluation, a warehouse should retain baseline data covering multiple replenishment cycles and both ordinary and exceptional demand. The analytical file should preserve all orders, not only those completed successfully, so that cancelled or rescheduled lines cannot disappear from the denominator. Direct costs need consistent allocation of energy, property, staffing, technology, depreciation and external transport. A simultaneous hospital-side account should record urgent purchasing, internal stock handling and missed delivery effects. Changes in product mix, case severity, contractual scope and supplier lead times should be reported alongside observed indicators. Without such controls, favourable cost-per-line movements may reflect accounting transfers rather than process improvement.

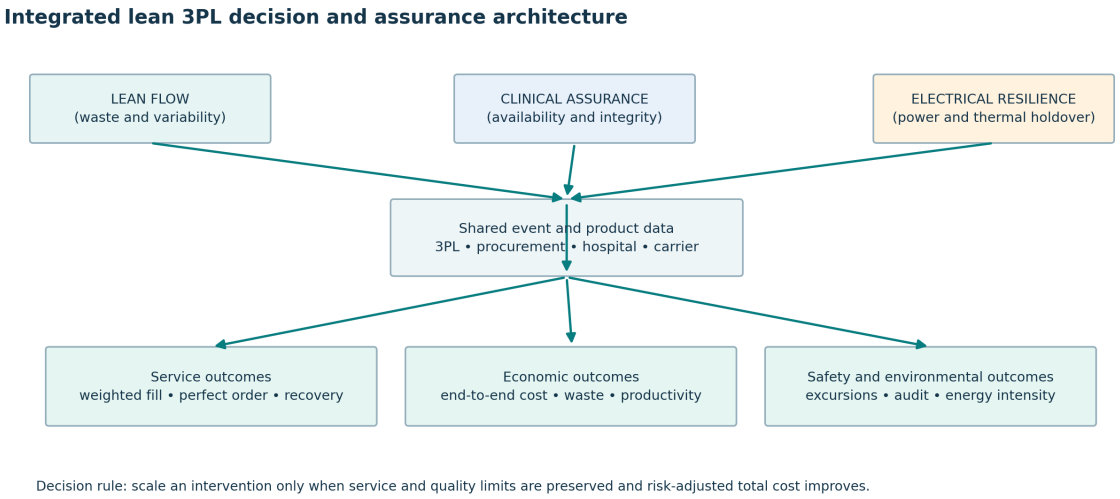


Figure 2. Integrated decision model linking lean flow, clinical assurance, electrical resilience and shared performance governance (original conceptual schematic)

Table 2. Proposed healthcare 3PL performance scorecard, definitions and balancing measures

Indicator	Operational definition	Primary data source	Required balancing check
Clinically weighted fill rate	Priority-weighted units supplied / required	Hospital order and shortage logs	Critical shortages and substitution events
Perfect-order delivery	Correct, timely, undamaged, traceable orders / all orders	WMS, TMS and proof of delivery	Temperature deviation and dispatch exclusions
Warehouse cost per accepted line	Full 3PL operating cost / accepted order lines	Activity ledger and finance records	Hospital transfer and emergency freight cost
Expiry-adjusted waste	Destroyed and obsolete stock value / average stock value	Batch ledger and approved disposal logs	Quarantine ageing and proactive reallocation
Picking productivity	Accepted lines / paid picking hours	WMS timestamps and labour roster	Picking errors, ergonomic events, fatigue
Cold-chain conformity	Validated shipments without unsafe excursion / applicable shipments	Calibrated sensors and deviation records	Sensor uptime, missing logs, alarms
Electricity intensity	Metered kWh / validated temperature-controlled pallet-days	Sub-metering and cold-room logs	Thermal compliance; backup test success

Indicator	Operational definition	Primary data source	Required balancing check
Recovery capability	Tested restoration time against clinically required limit	Incident logs, generator and system tests	Service losses during outage and failover

11 Critical discussion, research gaps and future directions

The evidence supports a conditional account of lean value rather than an uncomplicated efficiency narrative. Mapping and standardisation are credible routes to lower handling waste, but most published studies differ in geography, product scope and outcome definition. The Saudi shortage and inventory-waste studies establish material problems without proving that a specific 3PL intervention would solve them [3–5]. Technology reviews describe capabilities and barriers, not guaranteed pay-back [12–15]. Optimisation papers often assume stable, complete data and compliance rules that actual facilities struggle to provide [17–20]. Accordingly, the causal pathway from lean practice to lower Saudi system-wide cost remains a research proposition requiring observation.

Four research gaps deserve priority. First, few Saudi multisite evaluations connect 3PL process measurements with hospital stock-out severity and patient-facing outcomes. Second, published cost analyses rarely capture utility resilience, emergency transfers, temperature excursions and the hidden cost of clinical disruption. Third, evidence on how national procurement data should integrate with outsourced warehouse execution remains incomplete. Fourth, organisational consequences of lean automation, including workforce safety and professional judgement, need longer observation. These gaps can be addressed through pre-registered interrupted time-series designs, matched-depot comparisons, event-log process mining and mixed-method investigation of failure handling.

Future studies should publish transparent numerator and denominator definitions, facility characteristics, demand variability, product categories, power-availability conditions and full investment costs. A promising design would compare differentiated inventory policy against uniform minimum-stock reduction using clinically weighted service loss and expiry-adjusted total cost. Another would evaluate controlled-door operations, electrical sub-metering and standby-power testing against both energy intensity and temperature integrity. Multi-site experiments should explicitly capture spillovers: reduced warehouse expenditure may increase storage, emergency purchasing or staff workload at hospitals. Reporting uncertainties and adverse incidents is essential if lean policy is to produce transferable rather than promotional evidence.

An additional agenda concerns distributive equity. Efficiency programmes often privilege high-volume customers because each stop or order line is cheaper to serve. A national health system instead has reason to protect geographic access, rare therapies and small facilities that cannot justify frequent dedicated deliveries on commercial grounds. Future multi-objective models should evaluate distributional service outcomes explicitly, including critical coverage in remote regions and the reliability of emergency recovery. Governance research should test whether shared incentives and open event data reduce blame shifting between purchasing bodies, 3PLs and hospitals. Such evidence could clarify whether lean distribution improves the whole health system or merely shifts costs towards the least powerful participant.

12 Conclusion

Lean third-party logistics can strengthen Saudi healthcare distribution when it is applied as a disciplined system of waste identification, protected clinical flow and measurable learning. The most defensible near-term priorities are accurate data, standardised receiving, differentiated inventory control, thoughtful slotting, controlled exceptions and transparent performance governance. Digital automation and green technologies can extend these benefits, but only after process stability and safety requirements are demonstrated. Critically, electrical resilience belongs inside the operating model because loss of controlled storage or information continuity can outweigh routine efficiency savings. Under Vision 2030, progress should be assessed through reliable access to healthcare products, verifiable product integrity, efficient logistics resources and total cost across institutional boundaries. The proposed framework supplies testable propositions rather than invented numerical results and calls for Saudi-based longitudinal evaluation before broad claims of economic or clinical impact.

The framework also identifies a governance test: no proposed saving should be accepted until the organisations can trace its effects on critical product availability, temperature assurance, worker safety and recovery capability. Publication of operational data would help Saudi purchasers and logistics providers distinguish transferable methods from locally contingent interventions. This evidence discipline matters because the cost of failed distribution is not confined to the warehouse ledger. It can appear later as clinical disruption, replacement purchasing or loss of confidence in services.

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