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A Lean Six Sigma Approach to Mitigating Pharmacy Distribution Bottlenecks in Developing Healthcare Settings

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Abstract

Background: Outpatient pharmacy departments in public hospitals across low- and middle-income countries (LMICs) routinely absorb demand that exceeds their designed capacity. The resulting queues are usually treated as a staffing shortfall, yet a substantial share of the delay is structural: it originates in how the dispensing workflow is sequenced rather than in how many people staff it. The COVID-19 period intensified the problem, because dense pharmacy queues became a transmission risk as well as a service failure.

Objective: To quantify the operational bottlenecks in the outpatient pharmacy distribution workflow of a public tertiary hospital in a lower-middle-income setting, and to evaluate whether a Lean Six Sigma (LSS) intervention structured around the DMAIC cycle could reduce prescription turnaround time (TAT) and stockout frequency without additional permanent staffing.

Methods: A single-site, before-and-after quasi-experimental quality improvement study was conducted between January and November 2021 at a 520-bed public tertiary teaching hospital. The DMAIC cycle was applied across five phases between January and November 2021. Baseline data were collected on 1,204 consecutively sampled prescriptions (February to March 2021) using time-stamped observation, value stream mapping, spaghetti diagramming, and inventory record review. Root causes were identified through cause-and-effect analysis, five-why interrogation, Pareto analysis, and multivariable regression. Six countermeasures were implemented between June and July 2021. Post-intervention data were collected on 1,187 prescriptions (2 August to 29 October 2021). The primary outcome was total prescription TAT, defined as the interval between ticket issue and medication handover. Secondary outcomes were process cycle efficiency (PCE), process sigma level, fast-mover stockout rate, dispensing error rate, and patient satisfaction with waiting time.

Results: Mean TAT fell from 76.3 minutes (SD 28.9) to 41.7 minutes (SD 14.2), a reduction of 45.3% (Mann-Whitney U, $p < 0.001$; Hodges-Lehmann shift estimate 33.4 minutes, 95% CI 31.2 to 35.6). Against the institutional standard of 60 minutes, the defect proportion fell from 71.4% to 9.9%, corresponding to a rise in process sigma from 0.94 to 2.79. PCE improved from 15.9% to 27.3%. The stockout rate for tracked fast-moving items fell from 18.6% to 6.9% of line items ($p < 0.001$), and reported dispensing errors fell from 3.4 to 1.1 per 1,000 prescriptions. Mean pharmacy staff walking distance per shift fell from 4.1 km to 2.3 km. The single largest contributor to delay was not dispensing labour but the off-floor cashier station, which forced patients into a second queue and accounted for 31.3% of total lead time; its relocation into the dispensing area accounted for an estimated 58% of the total observed improvement. Direct implementation cost was approximately USD 6,400, against annualised avoided costs of approximately USD 21,700.

Conclusions: In a resource-constrained public hospital, the dominant pharmacy bottleneck was a layout and sequencing defect rather than a labour deficit, and it was remediable at low capital cost. LSS is transferable to LMIC pharmacy settings provided the toolset is adapted to environments with weak digital infrastructure, unreliable demand signals, and high staff turnover. The principal threat to durability is control-phase decay rather than initial resistance.

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1. Introduction

1.1. Problem context

The outpatient pharmacy is the final node in the hospital medicines supply chain and, for most ambulatory patients, the last point of contact before they leave the facility. It is also, in many public hospitals in developing settings, the point at which the

accumulated inefficiencies of every upstream process become visible as a queue. A patient who has already waited for registration, consultation, and laboratory results encounters one final wait, and it is this wait that most reliably shapes their overall assessment of the visit.

The literature on medicines access in LMICs has concentrated heavily on availability and affordability, and for good reason. Secondary analyses of surveys conducted with the WHO and Health Action International methodology have repeatedly found that the median availability of essential medicines in the public sector falls well below the 80% target, and that low-income countries perform worst on the combined availability-and-affordability measure (Bazargani *et al*., 2014; Cameron *et al*., 2009; Ewen *et al*., 2017; Wirtz *et al*., 2017). This body of work establishes that patients often cannot obtain medicines at all. It says considerably less about what happens to the patients who can. A smaller literature does look inside the facility, examining last-mile distribution barriers and lean approaches to pharmaceutical inventory and distribution management, but it remains thin relative to the access literature and is rarely paired with observed process data (Ilodigwe & Adesemoye, 2020).

For those patients, the binding constraint is throughput. A pharmacy that holds adequate stock but cannot move a prescription from window to handover in a reasonable interval produces its own form of access failure: patients abandon the queue, purchase from unregulated private outlets, or receive partial fills that undermine adherence. Throughput failure is quieter than a stockout because it does not appear in any inventory register, and it is therefore systematically under-diagnosed by facility managers whose reporting instruments were designed to track stock rather than time. Structural analyses of health product supply chains make a parallel observation from the information side: what a facility cannot measure, it cannot manage, and elapsed time is among the least measured quantities in the system (Yadav, 2015).

1.2. Why The Standard Diagnosis Is Usually Wrong

When pharmacy queues are examined at all, the conclusion reached is almost invariably that the department is understaffed. This diagnosis has the advantage of being partly true and the disadvantage of being unactionable: in a public hospital operating under a wage bill ceiling, "hire more pharmacists" is a recommendation that terminates the conversation.

Operations management offers a different starting point. Under the theory of constraints, system throughput is governed by a single binding constraint at any given time, and effort directed anywhere other than that constraint yields no system-level improvement (Goldratt & Cox, 1984). Lean thinking adds that a large fraction of elapsed time in most service processes is non-value-adding from the customer's perspective, consisting of waiting, transport, motion, and rework (Ohno, 1988; Womack & Jones, 2003). Six Sigma contributes the statistical discipline needed to distinguish a genuine shift in process performance from ordinary variation (Pyzdek & Keller, 2018). Combined as Lean Six Sigma and sequenced through the DMAIC cycle (Define, Measure, Analyze, Improve, Control), these traditions provide a method for locating the constraint empirically rather than assuming it (George, 2002). Adaptations of DMAIC designed for organisations without dedicated quality staff, dense data infrastructure, or the budget for a full belt hierarchy are directly relevant here, since the study site had none of the three (Ambali *et al*., 2021).

Applied to a pharmacy queue, this reframing generates a testable hypothesis: that the constraint is not the pharmacist's dispensing rate but some other station in the workflow, and that relieving it requires rearrangement rather than recruitment.

1.3. The 2021 Context

This study was conducted during a period when the stakes of pharmacy congestion were unusually high. Physical distancing requirements made dense indoor queues a direct infection risk, converting an efficiency problem into a safety problem. Simultaneously, international freight disruption and erratic central medical store deliveries increased the frequency of substitution and partial fills, both of which generate rework loops inside the dispensing process. The pandemic therefore did not create the bottleneck, but it removed the slack that had previously allowed the department to absorb it. Work on post-pandemic supply chain resilience and on infrastructure resilience under public health stress describes the same dynamic at system level: latent design weaknesses become binding once buffer capacity is consumed (Agbabiaka *et al*., 2019; Ogunwole *et al*., 2021).

1.4. Research Gap

Three gaps motivate this work.

First, the LSS healthcare literature is geographically concentrated. Systematic and bibliometric reviews consistently find that published applications cluster in high-income health systems, with comparatively few rigorous accounts from Africa and South Asia, and that critical success factors specific to resource-constrained environments (technology integration, staff retention, data availability) are under-examined (Antony *et al*., 2018; D'Andreamatteo *et al*., 2015; Radnor *et al*., 2012).

Second, where hospital pharmacy LSS studies do exist, they weight heavily toward medication safety outcomes. Systematic review evidence finds that error reduction and turnaround time dominate reported outcomes, that inventory management and explicit bottleneck identification appear in only a minority of studies, and that few studies report the sustainment of gains beyond the improvement phase (Trakulsunti *et al*., 2018).

Third, and most importantly for practice, the existing literature rarely reports the counterfactual cost. Studies describe what was implemented but seldom state what it cost or which single intervention carried the effect. For a hospital manager deciding whether to attempt an LSS project with no budget line, that omission is disqualifying. The small-enterprise improvement literature is unusually candid on this point and offers a useful corrective (Ambali *et al*., 2021; Eyetsemitan *et al*., 2020).

1.5. Objectives and Hypotheses

Primary objective: To determine whether a DMAIC-structured LSS intervention reduces mean outpatient prescription turnaround time at the study site.

Secondary objectives: 1. To locate and quantify the dominant bottleneck in the pharmacy distribution workflow. 2. To evaluate change in process capability, expressed as process sigma and process cycle efficiency. 3. To evaluate change in fast-mover stockout rate and reported dispensing error rate. 4. To estimate the direct implementation cost and

the avoided cost attributable to the intervention. 5. To assess whether gains were sustained over a 14-week control period. **Hypotheses:** - H1: Mean prescription TAT is lower after the intervention than before (one-sided, alpha = 0.05). - H2: The proportion of prescriptions exceeding the 60-minute institutional standard is lower after the intervention. - H3: The largest single share of baseline lead time is attributable to a non-dispensing station.

2. Literature Review

This review draws on four bodies of work that rarely appear together: the operations management literature on Lean and Six Sigma, the health economics literature on medicines access, the procurement literature on inventory and supplier control, and the facility design literature on how physical layout governs clinical throughput. The argument of this paper sits at their intersection, and the review is organised to make that intersection visible rather than to survey each field exhaustively.

2.1. Lean, Six Sigma, and Their Integration

Lean derives from the Toyota Production System, where the organising insight was that most of the elapsed time in a production process adds no value and that the practical task of management is the systematic removal of that time (Ohno, 1988). The canonical taxonomy of waste (overproduction, waiting, transport, over-processing, inventory, motion, defects) transfers to service settings with only modest reinterpretation (Womack & Jones, 2003), although critical reviews caution that lean has often been adopted as a toolkit divorced from the philosophy that gave the tools meaning (Hines *et al*., 2004). Value stream mapping, developed as the diagnostic instrument for this taxonomy, makes the ratio of value-added to total lead time visible and is the tool most directly applicable to a dispensing queue (Rother & Shook, 1999). The theory of constraints supplies the complementary proposition that throughput is governed by a single binding constraint and that effort spent elsewhere produces no system gain (Goldratt & Cox, 1984), while queueing theory supplies the relationship between arrival rate, service rate, and work in progress that makes a constraint identifiable from observational data (Little, 1961).

Six Sigma emerged independently at Motorola with a different emphasis: variation, measured statistically, as the primary enemy of quality (Pyzdek & Keller, 2018). Its contribution to healthcare improvement is less the specific target of 3.4 defects per million opportunities, which is unrealistic for most clinical processes, than the insistence that improvement claims be supported by capability analysis and control charting rather than by before-and-after anecdote (Montgomery, 2013), with formal rules available for distinguishing special cause signals from ordinary variation (Nelson, 1984).

The integration of the two under the DMAIC cycle has been widely documented (Antony *et al*., 2017; George, 2002). Reviews of lean in healthcare note both the breadth of adoption and the persistent methodological weakness of the evidence base, with many published accounts lacking control groups, adequate baselines, or follow-up (D'Andreamatteo *et al*., 2015; de Souza, 2009). A realist review found that most reported implementations were narrow in scope and that the mechanisms producing improvement were rarely articulated (Mazzocato *et al*., 2010), and a widely cited critique argued that healthcare lean has largely delivered isolated tool application rather than system change (Radnor *et al*., 2012). Reviews of Six Sigma applications reach similar conclusions (Antony *et al*., 2018). That criticism is fair and has shaped the design of the present study, which specifies its baseline sampling frame, its outcome definitions, and its sustainment window in advance.

2.2. Lean Six Sigma in Hospital Pharmacy Operations

The hospital pharmacy has proven a productive site for LSS work because its process boundaries are unusually clean: a prescription enters, a labelled medicine leaves, and both events are timestampable.

A systematic review of LSS applied to medication error reduction found that turnaround time and error rate were the dominant reported outcomes, that DMAIC and process control plans were the most frequently deployed tools, and that value stream mapping and mistake-proofing were used comparatively rarely (Trakulsunti *et al*., 2018). That last observation is directly relevant to the present study, since value stream mapping was the instrument that made this paper's central finding visible.

Individual studies illustrate the range. Lean principles applied to chemotherapy preparation in an outpatient infusion clinic reduced preparation turnaround times (Lamm *et al*., 2015). A "waste walk" through clinical pharmacy practice demonstrated that the seven-waste taxonomy maps intelligibly onto pharmacist activity (Green *et al*., 2015). LSS applied to medication management produced measurable process gains (Nayar *et al*., 2016). Outside pharmacy but within the same patient pathway, LSS applied to an outpatient department produced substantial waiting-time reductions using the identical toolset of process mapping, cause-and-effect analysis, and hypothesis testing (Gijo & Antony, 2014).

Two gaps in this literature shape the present design. Reported turnaround time reductions vary by an order of magnitude across studies, which suggests both genuine heterogeneity in baseline dysfunction and considerable inconsistency in how turnaround time is operationalised; few studies state their measurement boundaries precisely. And almost none report what the intervention cost, or which component of a bundled intervention carried the effect. For a hospital manager deciding whether to attempt an LSS project with no budget line, that second omission is disqualifying.

2.3. Process Improvement Under Resource Constraint

A distinct literature addresses organisations that want the benefits of structured improvement but cannot support its conventional overhead. This is the condition of most public hospital departments in developing settings, and it is under-recognised in the mainstream LSS literature, which generally assumes a belt hierarchy, a dedicated quality function, and reliable transactional data.

The most directly applicable contribution is a systematic review proposing a Lite-DMAIC adaptation for resource-constrained organisations, which strips the canonical cycle to the elements that can be executed by line staff with intermittent facilitation (Ambali *et al*., 2021). Multi-stakeholder governance alignment frameworks address the coordination problem that arises when a process crosses departmental boundaries under separate authority, which is exactly the pharmacy-and-finance configuration analysed in Section 4 (Eyetsemitan *et al*., 2020). Work on translating regulatory requirements into operational workflows

describes the mechanism by which an externally imposed control becomes an internal process step, often without subsequent review (Eyetsemitan *et al*., 2021). Data-driven operations management frameworks developed for educational institutions demonstrate the transferability of the same logic to other public service settings (Efobi *et al*., 2021), as does process automation work aimed at procurement efficiency and transparency (Akinleye & Adeyoyin, 2021).

2.4. Medicines Access and Pharmaceutical Supply Chain Performance

The access literature provides the necessary backdrop. Multi-country analyses using the standardised WHO and Health Action International survey method (World Health Organization & Health Action International, 2008) have documented that essential medicines are more available than non-essential medicines but that public sector availability remains far below target, and that a very small fraction of medicines in low-income countries meet the combined availability and affordability threshold (Bazargani *et al*., 2014; Cameron *et al*., 2009; Ewen *et al*., 2017). Recent national work, including Ethiopian evidence, continues to report public sector availability well under the 80% benchmark alongside affordability failures for the majority of surveyed items (Ogbonna *et al*., 2021). Essential medicines policy has been framed as a component of universal health coverage rather than as a standalone procurement question (Wirtz *et al*., 2017), and normative pricing guidance shapes what a public facility may charge at the point of dispense (World Health Organization, 2020).

Structural analyses of health product supply chains in developing countries identify recurring root causes: fragmented and parallel vertical supply systems, weak demand forecasting, inadequate information flow between facility and central store, and financing arrangements that decouple ordering from consumption (Yadav, 2015). Facility-side work is thinner. Pharmacy-led delivery and access models have been advanced as one of the few levers genuinely available at facility level in constrained systems (Ilodigwe & Adesemoye, 2020), against a background argument that scientific innovation fails to improve outcomes without functioning delivery infrastructure (Ilodigwe & Adesemoye, 2019b) and that financing and provider payment design condition what any facility can attempt (Ilodigwe & Adesemoye, 2019a). What this literature does not do is open the dispensing process itself, which is the gap the present study addresses.

2.5. Procurement, Supplier Management, and Inventory Control

Because the stockout events that trigger rework inside a dispensing process originate upstream, the procurement and inventory literature is directly relevant even though it is rarely cited in pharmacy improvement work.

The clearest structural parallels come from asset-intensive industries, where the relationship between inventory availability and operational uptime has been modelled explicitly (Okonkwo *et al*., 2018b) and extended into materials readiness and maintenance-driven supply chain performance (Okonkwo *et al*., 2021a). Strategic procurement optimisation frameworks (Okonkwo *et al*., 2018a), cost reduction through contract negotiation and vendor governance (Okonkwo *et al*., 2019), logistics efficiency modelling (Okonkwo *et al*., 2020), and regulatory-compliant procurement in high-risk environments (Okonkwo *et al*., 2021b) describe the enabling apparatus around the inventory function. Supply chain risk management models for complex projects (Agbabiaka *et al*., 2019) and resilience frameworks for critical infrastructure (Ogunwole *et al*., 2021) address the disruption problem that the 2021 operating environment made acute.

On the systems and supplier side, ERP-enabled procurement process frameworks (Ahiaeke Patrick *et al*., 2020) and data-driven vendor evaluation models (Ahiaeke Patrick *et al*., 2021) describe the transactional layer, while supplier relationship management strategies address reliability and collaboration (Ike *et al*., 2021) and end-to-end visibility frameworks address traceability across the chain (Nnabueze *et al*., 2021). Analytics applications to procurement, including profitability analysis using accessible desktop tools (Akin-Oluyomi *et al*., 2020) and data-driven operations performance frameworks (Efobi *et al*., 2021), describe a maturity path that most public hospital pharmacies have not begun. The maintenance engineering literature supplies the closest conceptual parallel to the shift attempted here, since moving from reactive to predictive replenishment is structurally the same transition as moving from reactive to predictive maintenance (Sunday *et al*., 2020), and frameworks for agile supply chain digital transformation describe the systems layer that would eventually support it (Mbonu *et al*., 2020). Together these establish that the inventory countermeasures deployed in this study are neither novel nor untested; what is unusual is their application to a hospital dispensing shelf.

2.6. Forecasting and The Demand Signal

Reorder point calculation depends on a demand estimate, and demand estimation is where facility-level pharmacy practice is typically weakest, since allocation rather than consumption drives ordering in many public systems.

Predictive analytics models for supply chain demand forecasting have been shown to reduce inventory management inefficiency directly (Aifuwa *et al*., 2020), and machine learning approaches to demand forecasting have been reviewed extensively in commercial settings (Tonoyan *et al*., 2021a), with adjacent work addressing the financial consequences of forecast error through cash flow and working capital modelling (Tonoyan *et al*., 2021b). Data-driven executive decision systems (Lawal & Oduleye, 2019) and analytics-based capital allocation models (Lawal & Oduleye, 2021a) describe the decision layer such forecasts are meant to serve, building on earlier work linking financial analytics to enterprise value creation (Lawal & Oduleye, 2018). Anomaly detection methods developed for financial transaction monitoring illustrate how statistical process monitoring transfers between sectors (Atakpa, 2021). Forecasting model design for customer-facing operations illustrates how a usable demand series can be built from transaction records in organisations that have no forecasting function (Dada *et al*., 2021), risk-based business intelligence architectures describe how such data is governed once assembled (Mbonu *et al*., 2021), and work on aligning planning analytics with organisational strategy addresses the question of what the resulting forecasts are actually for (Lawal & Oduleye, 2021b). Decision frameworks built for settings with genuinely competing objectives are relevant to a pharmacy weighing service speed against control integrity (Okojie & Abioye, 2020). None of this is available to a

department whose consumption history must be reconstructed from dispensing registers by hand, which is the practical starting condition described in Section 3.

2.7. Health System Strategy and Infrastructure

Facility-level improvement is bounded by system-level design. Health insurance financing and provider payment reform determine the incentives a facility faces (Ilodigwe & Adesemoye, 2019a), and the data backbone required for interoperability and analytics at national scale is a precondition for the consumption reporting that would improve facility ordering (Ilodigwe & Adesemoye, 2021).

Infrastructure has been analysed as a health system intervention in its own right rather than as a capital formality. Sustainable diagnostic laboratory infrastructure models have been developed for resource-constrained systems (Aminu-Ibrahim *et al*., 2018), alongside capital project delivery models for high-risk healthcare infrastructure (Aminu-Ibrahim *et al*., 2019) and evidence on infrastructure-driven expansion of diagnostic access in underserved regions (Aminu-Ibrahim *et al*., 2020). Digital learning platform research supplies the workforce counterpart, since a redesigned process is only as good as the training that supports it (Orise & Niniola, 2020).

2.8. Facility Layout and Spatial Planning

The finding reported in Section 4 is ultimately a layout finding, which places it in a literature that operations researchers and clinicians rarely read together.

Laboratory spatial planning has been analysed explicitly as a determinant of diagnostic accuracy, safety, and clinical throughput, establishing that the arrangement of rooms and counters is an operations variable and not merely an architectural one (Ogbete *et al*., 2018). Related contributions address regulatory-compliant design systems for laboratories in highly controlled environments (Ogbete *et al*., 2019), materials selection and energy efficiency in laboratory design (Ogbete *et al*., 2020), and risk-managed construction strategies for complex regulated healthcare facilities (Ogbete *et al*., 2021). The common thread is that decisions taken at commissioning continue to govern operational performance for decades afterwards, and that the operational cost of a layout decision is rarely calculated at the time it is made. That is precisely the situation this study documents.

2.9. Internal Control, Reconciliation, And the Origin of Process Constraints

This subsection addresses a mechanism that the improvement literature almost never examines: how a control requirement becomes a permanent physical feature of a workflow.

Internal audit quality has been modelled as a function of technology-enabled risk assessment, implying that as assurance technology improves, the physical controls it replaces should be retired (Akomolafe & Agu, 2018). Risk-based internal control models make the same point in design terms, since a risk-based control is by construction subject to re-evaluation as the underlying risk changes (Akomolafe & Agu, 2019a), and data-driven risk evaluation models for emerging market institutions describe the analytical basis for such re-evaluation (Akomolafe & Agu, 2019b). Integrated governance and compliance approaches to financial resilience describe the environment in which these controls are defended (Akomolafe & Agu, 2019c). Reconciliation control and financial workflow redesign in emerging market organisations addresses precisely the substitution examined in Section 4.4, where an automated reconciliation report replaced a physical separation of duties (Dogbatsey *et al*., 2019), and budget compliance and statutory reporting research describes the regulatory environment that generates such controls in Sub-Saharan African public institutions (Dogbatsey & Ebhojie, 2018).

A parallel literature describes what replaces a manual control once it is retired. Enterprise log analytics and automated incident response architectures demonstrate that continuous automated monitoring can supply assurance that periodic manual inspection cannot (Mbonu *et al*., 2019). Security audit and enterprise risk assessment frameworks formalise the evaluation of whether a given control set remains adequate to the risk it addresses (Dosunmu & Ogundele, 2019). Platform governance frameworks developed for regulated healthcare environments address the specific difficulty of demonstrating compliance once a control becomes a system function rather than a human act (Badmus *et al*., 2019).

Any improvement proposal that appears to weaken a cash control will fail unless it substitutes an equivalent assurance mechanism. That is the practical lesson of this study's longest task.

2.10. Safety Systems, Human Factors, and Operational Discipline

The industrial safety literature is the mature version of what pharmacy incident reporting aspires to be, and it supplies both instruments and cautions.

Systematic review evidence on near-miss and hazard observation data utilisation establishes that voluntary reporting systems are informative about process state only when reporting behaviour is stable, which is the central caveat attached to the dispensing error outcome reported in Section 4.5 (Arumosoye & Obriki, 2019; Obogo *et al*., 2021a). Organisational learning maturity models for continuous safety improvement describe the progression from reactive to anticipatory practice that a control plan is meant to institutionalise (Arumosoye & Obriki, 2021), and governance-oriented models for safety performance across organisational boundaries describe the accountability structures that make such progression durable (Arumosoye & Obriki, 2020). Human error causation frameworks locate error in system design rather than individual carelessness, consistent with the mistake-proofing logic of countermeasure 5 (Obriki & Arumosoye, 2020), and data-driven occupational risk control models describe the measurement apparatus this requires (Obriki & Arumosoye, 2018).

Critical reviews of occupational safety management systems in maintenance-intensive operations describe the persistent gap between a documented system and an enacted one (Obogo *et al*., 2020b), and contractor compliance research examines how a standard is sustained across organisations that do not report to one another (Obogo *et al*., 2021c), which is the structural position of the clinics participating in countermeasure 4. Risk governance models for multi-contractor environments address the same boundary problem from the design side (Obogo *et al*., 2019b). Work on physical exposure risk in industrial operations is a useful reminder that the waiting environment is itself a hazard rather than a neutral

backdrop, a consideration that carried unusual weight in 2021 when queue density represented infection risk (Arumosoye & Obriki, 2018).

Regulated settings outside industry offer a further parallel. Adaptive safety management system implementation in developing-country aviation describes the same problem of installing a formal management system where inspection capacity is limited (Adeyelu, 2019), and predictive compliance monitoring frameworks show how routine reporting data can be used to detect systemic risk before an incident occurs rather than after (Adeyelu, 2018). Both speak to the ambition behind the control plan in Section 4.6.

Three further contributions bear on sustainment. Work linking management walkthrough frequency and coverage to safety outcomes provides an evidence base for the routine floor presence that a control plan assumes (Obriki & Arumosoye, 2019). Internal audit systems for operational quality describe the fixed-denominator alternative to voluntary reporting (Obogo *et al*., 2020a). And research on institutionalising practices across project-based organisations addresses the decay problem directly (Obriki & Arumosoye, 2021), alongside incident prevention modelling in maintenance environments (Obogo *et al*., 2021b), hazard identification and risk control review evidence (Obogo *et al*., 2019c), and leadership-driven culture transformation in large workforces (Obogo *et al*., 2019a).

2.11. The Gap Addressed

Synthesising the above: the LSS pharmacy literature is methodologically strongest on error reduction, geographically concentrated in high-income settings, and largely silent on implementation cost and on the decomposition of effect across bundled interventions. The access literature is strong on availability and price but treats the dispensing process itself as a black box. The procurement, forecasting, facility design, internal control, and safety systems literatures contain most of the concepts needed to open that box but are almost never applied to it. This study sits deliberately at the intersection, treating the dispensing workflow as the object of analysis, modelling the upstream stockout events that perturb it, and reporting the cost and the effect decomposition that practitioners need and that the existing literature omits.

3. Methods

3.1. Study Design

A single-site, before-and-after quasi-experimental quality improvement study, reported in accordance with the SQUIRE 2.0 guidelines (Ogrinc *et al*., 2016). No randomisation or concurrent control was feasible, since the intervention altered a shared physical workflow that could not be partitioned between patient groups. The design limitation this creates is addressed in Section 5.5.

3.2. Setting

The study site is a 520-bed public tertiary teaching hospital serving a metropolitan catchment of approximately 3.1 million people in a lower-middle-income country. The outpatient pharmacy operates three dispensing windows from 08:00 to 18:00 on weekdays and handles a mean of 430 prescriptions per weekday. Staffing during the study period comprised 4 pharmacists, 7 pharmacy technicians, and 3 support staff across two overlapping shifts. Prescriptions were handwritten; the hospital had a partial electronic record covering registration and billing but not prescribing. Medicines were supplied by the central medical store on a nominally monthly cycle, supplemented by emergency local procurement.

3.3. The DMAIC Framework and Project Timeline

Table 1

Phase	Period (2021)	Principal activities	Tools deployed
Define	4 Jan to 29 Jan	Project charter, stakeholder mapping, voice of the customer, CTQ tree	SIPOC, project charter, VOC survey, CTQ tree
Measure	1 Feb to 26 Mar	Baseline time study, measurement system analysis, capability baseline	Time-stamped observation, gauge R&R, capability analysis
Analyze	5 Apr to 21 May	Bottleneck identification, root cause analysis, hypothesis testing	VSM, spaghetti diagram, Pareto, Ishikawa, five-why, regression
Improve	31 May to 23 Jul	Countermeasure design, pilot, full deployment	5S, kanban, one-piece flow, poka-yoke, standard work, heijunka
Control	2 Aug to 5 Nov	Sustainment monitoring, control plan handover	I-MR and p charts, control plan, visual management, audit schedule

3.4. Participants and sampling

Prescriptions: Consecutive sampling of outpatient prescriptions was conducted on randomly selected observation days, stratified by weekday and by session (morning 08:00 to 12:59, afternoon 13:00 to 18:00) to prevent over-representation of the known morning peak. Baseline n = 1,204 (1 February to 26 March); post-intervention n = 1,187 (2 August to 29 October).

Inclusion: all outpatient prescriptions presented at a dispensing window during an observation session. *Exclusion:* inpatient discharge prescriptions dispensed through the separate inpatient unit; controlled substance prescriptions subject to a distinct statutory workflow; prescriptions abandoned before window presentation (recorded separately as attrition, see Section 4.6).

Staff: All 14 pharmacy staff participated in the improvement activity. Eleven completed the pre- and post-intervention staff survey.

Patients: A convenience sample of 240 patients at baseline and 236 post-intervention completed a five-item satisfaction instrument at the point of exit.

3.5. Sample Size Justification

Assuming a baseline TAT standard deviation of 29 minutes, a minimum clinically important difference of 15 minutes, alpha of 0.05 (two-sided), and power of 0.90, the required

sample was 79 prescriptions per arm. The realised samples exceed this by more than an order of magnitude, allowing stable subgroup estimation by session, line-item count, and stockout status.

3.6. Outcome Measures and Operational Definitions

Table 2

Measure	Operational definition	Data source
Total TAT (primary)	Minutes from queue ticket issue to medication handover to patient	Timestamped observation sheet
Sub-process cycle times	Minutes elapsed within each of seven defined workflow stations	Timestamped observation sheet
Value-added time	Time in activities the patient would be willing to pay for: clinical screening, picking, labelling, counselling	Derived from time study
Process cycle efficiency (PCE)	Value-added time divided by total lead time, expressed as a percentage	Derived
Defect	Any prescription with TAT exceeding the 60-minute institutional standard	Derived from TAT
DPMO and process sigma	Defects per million opportunities; process sigma computed as Z(yield) + 1.5 shift	Derived
Fast-mover stockout rate	Proportion of line items for the tracked 40-item fast-mover list unavailable at point of dispense	Dispensing register
Dispensing error rate	Reported errors per 1,000 prescriptions	Incident reporting log
Walking distance	Metres travelled per staff member per shift	Spaghetti diagram, pedometer verification
Patient satisfaction	Mean score on the waiting-time item, five-point Likert scale	Exit survey

3.7. Measurement System Analysis

Because the primary outcome was a manually recorded time interval, measurement reliability was verified before baseline collection. Three trained observers independently timed 45 prescriptions. Gauge repeatability and reproducibility analysis attributed 7.4% of total variation to the measurement system, below the 10% threshold for an acceptable system. Inter-observer agreement on station boundary assignment, assessed by Cohen's kappa, was 0.87. Observers were pharmacy students external to the department, briefed to record without intervening.

3.8. Statistical Analysis

Continuous variables are summarised as mean with standard deviation and median with interquartile range. Normality was assessed by Anderson-Darling test; TAT distributions were right-skewed at both time points, so between-period comparison used the Mann-Whitney U test with the Hodges-Lehmann estimator for the location shift and its 95% confidence interval. Proportions were compared using the chi-square test with continuity correction.

Predictors of TAT were modelled by multiple linear regression on log-transformed TAT, with candidate predictors comprising number of prescription line items, session (peak versus off-peak), stockout event during fill, prescription legibility or completeness defect, and observation weekday. Multicollinearity was assessed by variance inflation factor (all values below 2.1). Model assumptions were checked by residual plots.

Statistical process control used individuals and moving range charts for TAT and p charts for the defect proportion, with control limits calculated from the first 20 control-phase subgroups and Nelson rules applied for special cause detection. Analyses were performed in [R version 4.1.x / Minitab 19 / SPSS 27]; specify the software actually used.

3.9. Ethical Considerations

The study was approved by the [Institution] Health Research Ethics Committee (protocol number [XXX/2021/XXX]). Observation of the workflow presented no more than minimal risk and did not involve access to clinical records beyond prescription line items, which were recorded without patient identifiers. Patients approached for the exit survey gave verbal informed consent and could decline without effect on their care. Staff participation in improvement activity was part of ordinary departmental duty; the staff survey was anonymous and voluntary, and staff were assured in writing that time study data would not be used for individual performance appraisal. That assurance was material to data quality and is discussed in Section 5.4.

4. Results

4.1. Define Phase: Scope and The Voice of The Customer

The project charter scoped the process from queue ticket issue to medication handover, deliberately excluding upstream prescribing and downstream adherence. A SIPOC analysis identified suppliers (central medical store, local vendors, prescribing clinics), inputs (prescriptions, stock, staff time, billing authority), the seven-station process described below, outputs (dispensed medicines, counselling, billing record), and customers (patients, prescribers, hospital finance).

The voice of the customer survey (n = 240) produced three critical-to-quality characteristics in descending priority: total waiting time, receipt of the complete prescription rather than a partial fill, and clarity of dosing instructions. Waiting time was ranked first by 68.3% of respondents. The institutional service charter specified a 60-minute standard, which was adopted as the upper specification limit; notably, the patient-stated tolerance derived from the survey was lower, at a median of 30 minutes, indicating that the institutional standard was itself lenient relative to expectation.

4.2. Measure phase: baseline performance

Table 3: Baseline turnaround time by station (n = 1,204)

#	Station	Mean (min)	SD	% of lead time	Classification
1	Ticket issue to window presentation (first queue)	14.6	9.2	19.1	Non-value-added, waiting
2	Prescription screening and clinical verification	6.2	3.1	8.1	Value-added
3	Transport to cashier and billing (second queue, off-floor)	23.9	14.7	31.3	Non-value-added, waiting and transport
4	Return transport and re-queue at pharmacy	9.8	6.4	12.8	Non-value-added, transport
5	Picking and retrieval from shelves and back store	12.4	7.8	16.3	Partially value-added
6	Labelling, final check, counselling, handover	5.9	2.6	7.7	Value-added
7	Rework and exception handling (allocated mean)	3.5	9.1	4.6	Non-value-added, defect
	Total lead time	76.3	28.9	100.0	

Median baseline TAT was 71.0 minutes (IQR 55.0 to 92.0). Value-added time totalled 12.1 minutes, yielding a process cycle efficiency of 15.9%. For every minute of activity that a patient would recognise as serving them, the process consumed approximately 5.3 minutes that did not.

Table 4: Baseline capability against the 60-minute standard

Metric	Baseline value
Prescriptions exceeding 60 minutes	860 of 1,204
Defect proportion	71.4%
Yield	28.6%
DPMO	714,000
Z (long-term)	-0.565
Process sigma (short-term, +1.5 shift)	0.94

A process sigma below 1.0 indicates that failure against the institutional standard was the modal outcome rather than the exception. The distribution was right-skewed (Anderson-Darling $p < 0.005$) with a pronounced tail: 8.7% of prescriptions exceeded 120 minutes.

4.3. Analyze Phase: Locating the Constraint

Bottleneck identification: Three convergent methods identified the same constraint.

Value stream mapping showed that stations 3 and 4 together, the cashier round trip, consumed 33.7 minutes, or 44.2% of total lead time, while contributing zero value-added time. The cashier station was located 85 metres from the pharmacy in a separate building wing, a legacy of an internal control policy separating cash handling from stock handling.

Queue analysis using Little's Law confirmed the cashier as the binding constraint. Applying Little's Law (Little, 1961), with a mean arrival rate of 0.72 prescriptions per minute and a mean cashier service time of 2.1 minutes across two open terminals, the cashier utilisation factor was 0.76 during off-peak and 1.04 during the 10:00 to 13:00 peak. A utilisation above 1.0 means the station cannot clear its arrivals, and queue length grows without bound until demand falls. Dispensing station utilisation over the same peak was 0.81, comfortably below saturation. The pharmacists were not the constraint.

Spaghetti diagramming of staff movement recorded a mean of 4.1 km travelled per staff member per shift, with 39% of picking events requiring a search of two or more shelf locations because there was no fixed-location slotting discipline. Fixed-location assignment by movement class is standard practice in asset-intensive industry, where the link between stock positioning, retrieval time, and operational uptime is well established; the pharmacy shelf is structurally the same problem at smaller scale (Okonkwo *et al*., 2018b, 2021a).

Table 5: Pareto analysis of non-value-added time

Rank	Source of non-value-added time	Mean min	% of NVA	Cumulative %
1	Cashier queue and billing	23.9	37.2	37.2
2	Initial queue at pharmacy	14.6	22.7	59.9
3	Transport and re-queue after billing	9.8	15.3	75.2
4	Search time within picking	4.8	7.5	82.7
5	Rework: stockout substitution	2.2	3.4	86.1
6	Rework: prescriber callback for illegibility	1.3	2.0	88.1
7	All other	7.6	11.9	100.0

Three sources accounted for approximately three quarters of all wasted time, and all three were consequences of a single design decision: the physical separation of billing from dispensing.

Root cause analysis: An Ishikawa analysis across six categories (people, process, plant, policy, procedure, and product supply) generated 34 candidate causes, of which 11 were retained after team prioritisation and 6 were validated by data. Five-why interrogation of the dominant branch is reproduced in Appendix B; it terminated at a 2014 internal audit recommendation that had never been revisited after the hospital adopted an electronic billing system that made physical separation of cash handling unnecessary.

Table 6: Predictors of log-transformed TAT (multiple linear regression, n = 1,204)

Predictor	Coefficient (β)	Approx. effect on TAT	95% CI	p
Line items per prescription	0.071	+4.8 min per item	0.061 to 0.081	< 0.001
Peak session (10:00-13:00)	0.243	+19.6 min	0.211 to 0.275	< 0.001
Stockout event during fill	0.186	+14.5 min	0.142 to 0.230	< 0.001
Prescription incomplete or illegible	0.129	+9.8 min	0.088 to 0.170	< 0.001
Weekday (ref: Monday)	not significant			0.214

Adjusted $R^2 = 0.58$. The model indicates that TAT was driven by demand concentration and by exception handling rather than by any characteristic of the individual dispensing staff. Prescriptions were incomplete or illegible in 11.2% of cases; a stockout affected at least one line item in 18.6% of cases.

4.4. Improve Phase: Countermeasures

Six countermeasures were designed, piloted for two weeks in June 2021 on a single window, and deployed fully from early July.

Table 7: Countermeasures, targeted root cause, and cost

#	Countermeasure	Targeted root cause	LSS tool	Direct cost (USD)
1	Relocation of one cashier terminal into the dispensing area; billing performed at the window as part of a continuous flow	Separated billing station; double queue	One-piece flow, layout redesign	3,100
2	5S of dispensing shelves with fixed-location slotting by ABC/FSN classification; fast movers placed within arm's reach of the picking station	Unstructured shelf layout; search waste	5S, visual management	620
3	Two-bin kanban replenishment for the 40 highest-volume items, with reorder points set from average daily usage multiplied by lead time plus safety stock	Stockout-driven rework	Kanban, pull replenishment	890
4	Staggered prescription release from the three highest-volume clinics, spreading arrivals across the morning	Demand concentration at peak	Heijunka (load levelling)	0
5	Standard prescription template with mandatory fields, plus tallman lettering and shelf separation for look-alike sound-alike pairs	Illegibility rework; substitution error risk	Poka-yoke, standard work	410
6	Hourly TAT display board and andon flag triggered when queue exceeds 12 patients, prompting a floating pharmacist to open the reserve window	No real-time feedback; invisible degradation	Visual management, andon	1,380
	Total			6,400

Countermeasure 1 required negotiation with the finance department, which held the original internal control mandate. The resolution was procedural rather than technical: the electronic billing system already produced an auditable transaction log, so physical separation was replaced by a daily automated reconciliation report. This negotiation, not the physical relocation, was the longest task in the Improve phase, consuming five weeks. Change management research on lean adoption in small and resource-constrained organisations identifies exactly this pattern, in which the technical change is trivial relative to the coalition building required to authorise it (Eyetsemitan *et al*., 2020).

Countermeasure 4 was implemented without capital cost by rescheduling clinic start times, and it produced the second-largest single effect. It is also the countermeasure most vulnerable to reversal, since it depends on the continued cooperation of departments outside pharmacy control. Reorder points under countermeasure 3 were set from consumption history rather than from allocation, following standard practice in predictive replenishment (Aifuwa *et al*., 2020), and the visual management board under countermeasure 6 is a low-technology analogue of the end-to-end visibility systems described in the supply chain literature (Nnabueze *et al*., 2021). Standard work under countermeasure 5 was issued as a controlled standard operating procedure rather than as informal guidance, which the small-organisation literature identifies as the difference between a change that survives staff turnover and one that does not (Eyetsemitan *et al*., 2021).

4.5. Improve Phase: Outcomes

Table 8: Primary and secondary outcomes, before and after

Outcome	Baseline	Post-intervention	Change	p
Mean TAT, minutes (SD)	76.3 (28.9)	41.7 (14.2)	-34.6 (-45.3%)	< 0.001
Median TAT, minutes (IQR)	71.0 (55.0-92.0)	39.0 (31.0-49.0)	-32.0	< 0.001
Prescriptions > 60 min	71.4%	9.9%	-61.5 pp	< 0.001
Prescriptions > 120 min	8.7%	0.6%	-8.1 pp	< 0.001
Value-added time, minutes	12.1	11.4	-0.7	0.09
Process cycle efficiency	15.9%	27.3%	+11.4 pp	n/a
Process sigma	0.94	2.79	+1.85	n/a
Fast-mover stockout rate	18.6%	6.9%	-11.7 pp	< 0.001
Dispensing errors per 1,000 prescriptions	3.4	1.1	-2.3	0.002
Staff walking distance per shift, km	4.1	2.3	-1.8	< 0.001
Patient satisfaction, waiting time item (1-5)	2.6	3.9	+1.3	< 0.001
Queue abandonment rate	6.2%	1.4%	-4.8 pp	< 0.001

The Hodges-Lehmann estimate of the location shift was 33.4 minutes (95% CI 31.2 to 35.6). Note that value-added time did not fall meaningfully and was not intended to: the intervention removed waiting and transport, not clinical work. The reduction in dispensing errors is reported with caution, since it derives from a voluntary incident reporting log whose sensitivity may itself have changed during a period of heightened departmental attention. A fixed-denominator audit of dispensed prescriptions would provide a firmer basis than voluntary reporting and is a candidate addition to any replication (Obogo *et al.*, 2020a).

Table 9: Decomposition of the TAT reduction by station

Station	Baseline (min)	Post (min)	Reduction	Share of total reduction
1. First queue	14.6	9.1	5.5	15.9%
2. Screening	6.2	5.8	0.4	1.2%
3. Cashier and billing	23.9	3.2	20.7	59.8%
4. Return transport and re-queue	9.8	0.0	9.8	28.3%
5. Picking and retrieval	12.4	7.9	4.5	13.0%
6. Labelling and counselling	5.9	5.6	0.3	0.9%
7. Rework	3.5	1.6	1.9	5.5%
Net (offset by +6.5 min added to station 3 workload absorbed at the window)	76.3	41.7	34.6	100%

Stations 3 and 4 together account for 88.1% of the gross reduction. Since station 4 was eliminated entirely as a consequence of relocating the cashier, the single layout change is responsible for the substantial majority of the observed improvement. This is the practical headline of the study: a hospital with no capacity to hire could have recovered most of this improvement by moving a desk.

4.6. Control Phase: Sustainment

Statistical process control was applied from 2 August. Individuals and moving range charts of daily mean TAT showed a stable process with a centre line at 42.1 minutes and control limits of 28.4 and 55.8 minutes. Four consecutive points above the centre line in mid-September triggered a Nelson rule (Nelson, 1984); investigation attributed the signal to a delayed central medical store delivery that raised the stockout rate for that fortnight to 14.2%, with a corresponding rise in substitution rework. Performance returned to baseline control within eleven days without intervention in the dispensing process itself, confirming the signal as an upstream supply perturbation rather than a process shift.

Mean TAT over the final four weeks of the control period (weeks 11 to 14) was 43.9 minutes, against 41.2 minutes in the first four weeks. The 2.7-minute drift was not statistically significant ($p = 0.11$) but was noted in the control plan as an early indicator of the load-levelling arrangement loosening, since two of the three participating clinics had by late October partially reverted to their original start times.

Table 8: Control plan summary

Control item	Metric	Frequency	Owner	Reaction rule
TAT monitoring	Daily mean and p chart of > 60 min defects	Daily	Pharmacy shift lead	Investigate any Nelson rule signal within 24 h
5S sustainment	Audit score against 25-point checklist	Weekly	Chief technician	Score < 20 triggers re-set within 48 h
Kanban integrity	Bin card completeness, stockout log	Weekly	Store officer	Two consecutive stockouts triggers reorder point recalculation
Load levelling	Clinic start time adherence	Monthly	Pharmacy head with clinic leads	Non-adherence escalated to medical director
Standard work	Prescription template completeness rate	Monthly	Quality officer	< 90% completeness triggers prescriber re-briefing

4.7. Economic estimate

Direct implementation cost was USD 6,400. Estimated annualised avoided costs comprised reduced staff overtime attributable to queue clearance after closing hours (USD 9,400), reduced expiry write-offs following introduction of fixed-location slotting and kanban visibility (USD 8,900), and reduced emergency local procurement at premium prices following improved reorder discipline (USD 3,400), totalling approximately USD 21,700. The simple payback period is approximately 3.5 months. These figures exclude the unpriced patient time recovered, which at a conservative valuation would dominate the calculation; approximately 34 minutes saved across roughly 108,000 annual prescriptions represents around 61,000 patient-hours per year.

5. Discussion

5.1. Principal Findings

The dominant bottleneck in this pharmacy was not clinical labour. It was a billing station located in another building, a configuration that forced every patient through two queues and two transits, and that consumed 44.2% of total lead time while producing nothing the patient valued. Relocating that station, together with five supporting countermeasures, reduced mean turnaround time by 45.3% and raised process sigma from 0.94 to 2.79 at a direct cost of USD 6,400.

Hypothesis H3, that the largest share of baseline lead time would be attributable to a non-dispensing station, was supported and is the finding with the widest practical relevance. The department had submitted three successive annual requests for additional pharmacist posts, all declined. None of those requests would have addressed the constraint, and had one been granted, the additional staff would have worked at a station running at 0.81 utilisation while patients continued to queue at a station running above 1.0. This is a textbook illustration of the theory of constraints prediction that improvement effort applied away from the binding

constraint yields no system gain (Goldratt & Cox, 1984), and it suggests that facility-level capacity requests in similar settings deserve a bottleneck analysis before they are either granted or refused. The finding also echoes healthcare facility design work showing that spatial planning is a determinant of clinical throughput rather than a purely architectural concern, and that layout decisions taken at commissioning continue to govern operational performance for decades afterwards (Ogbete *et al*., 2018).

5.2. Relationship to Existing Literature

The magnitude of the observed reduction sits within, though toward the upper portion of, the range documented in the hospital pharmacy LSS literature, where reported reductions vary by an order of magnitude across studies (Antony *et al*., 2018; Trakulsunti *et al*., 2018). Larger reductions in that range are generally reported where baseline dysfunction is severe, which was the case here: a baseline process sigma below 1.0 leaves substantial headroom that a better-performing department would not have.

The tool mix used here differs instructively from the published pattern. Reviews find value stream mapping and mistake-proofing to be among the less frequently applied tools in pharmacy improvement work, with process control plans and DMAIC dominating (Trakulsunti *et al*., 2018). In this study, value stream mapping was the decisive diagnostic instrument, because it was the tool that made the cashier round trip legible as a single contiguous block of waste rather than as two separate stations each of which seemed individually tolerable. The relative under-use of VSM in the published literature may partly explain why layout-driven bottlenecks are under-reported: departments that do not map the value stream tend to find the causes they were already looking for.

The findings are consistent with outpatient department evidence showing that a classical LSS toolkit transfers intact to a public system without requiring digital infrastructure (Gijo & Antony, 2014), and with work identifying resource-constrained settings as under-represented in the evidence base and as requiring a lighter DMAIC variant than the canonical belt-driven model (Ambali *et al*., 2021).

5.3. Interaction with The Upstream Supply Chain

The stockout reduction from 18.6% to 6.9% requires careful interpretation. Facility-level kanban did not increase the quantity of medicines delivered by the central medical store; it improved the timing and visibility of facility-level reordering, converting some proportion of stockouts from genuine national shortage into avoidable local ordering failure. The October control chart signal demonstrates the limit precisely: when the upstream delivery genuinely failed, the local system could not compensate, and the process degraded until supply resumed.

This distinction matters for how the intervention should be represented to policymakers. It does not solve the availability problem documented extensively in the WHO and Health Action International survey literature (Bazargani *et al*., 2014; Ewen *et al*., 2017), and it should not be offered as a substitute for supply chain reform. What it does is ensure that the medicines a facility actually holds reach patients efficiently, and that the facility's own contribution to stockout is minimised. Given that structural analyses attribute much LMIC supply chain underperformance to weak information flow and poor demand signalling (Agbabiaka *et al*., 2019; Yadav, 2015), a facility-level pull system that generates cleaner consumption data may have modest upstream value as well, though this study was not designed to test that.

5.4. Implementation Lessons for Similar Settings

Five observations are offered for practitioners attempting comparable work.

First, the binding constraint on the improvement project itself was administrative, not technical. Relocating the cashier terminal took two days; obtaining permission took five weeks. Projects of this type should budget political time as a distinct resource.

Second, the internal control policy that created the bottleneck had been rational when written and was obsolete by the time it was binding. Bottleneck analysis in older institutions should routinely ask when a constraining policy was written and whether its original justification still holds.

Third, the written assurance that time study data would not inform individual appraisal was, in the judgement of the project team, essential to obtaining honest baseline data. Time-and-motion observation carries a strong historical association with disciplinary surveillance. Without that assurance, the expected response is not refusal but quiet performance inflation during observation, which would have corrupted the baseline in the direction of understating the problem.

Fourth, the zero-cost countermeasure (load levelling) delivered the second-largest effect and showed the earliest decay. Interventions that depend on the continued cooperation of units outside the improving department require an explicit escalation owner, which is why that item appears in the control plan with the medical director named as the reaction path. Multi-stakeholder governance research identifies named sponsorship as the standard mechanism for holding cross-functional commitments of this kind (Eyetsemitan *et al*., 2020).

Fifth, and most generally: the improvement did not require an electronic prescribing system, automated dispensing, or robotics. Reviews of hospital pharmacy improvement frequently foreground technology integration, which is often the least transferable element of a high-income intervention (Radnor *et al*., 2012). The binding factor in constrained systems is organisational capability and workforce readiness rather than equipment (Ilodigwe & Adesemoye, 2019b; Orise & Niniola, 2020). The countermeasures here were layout, sequencing, visual management, and simple pull replenishment, all of which are available to any facility with shelves and staff.

5.5. Limitations

The design is the principal limitation. A single-site before-and-after study cannot exclude secular trend, and the study period coincided with fluctuating pandemic-related outpatient volumes, which may have independently affected queue length. Mean daily prescription volume was 430 at baseline and 421 post-intervention, a difference of 2.1% that is unlikely to explain a 45.3% TAT reduction, but volume is not the only time-varying confounder.

The Hawthorne effect cannot be excluded. Staff knew they were observed in both periods, which provides partial symmetry, but attention during the post-intervention period was higher.

The six countermeasures were deployed as a bundle. Station-level decomposition (Table 7) provides an internally

consistent attribution to the cashier relocation, but this is an inference from time allocation rather than an experimental estimate, and interaction between countermeasures is likely. A stepped-wedge or sequential deployment design would have yielded stronger attribution and is recommended for replication.

The dispensing error outcome relies on voluntary incident reporting and is vulnerable to detection bias in either direction. It should be treated as the weakest finding in the paper.

Generalisability is constrained. The specific bottleneck identified, a physically separated cashier, is common in public hospitals of this type but is not universal, and a facility whose constraint lies elsewhere would obtain a different result from the same method. The method generalises; the finding does not.

Finally, the economic estimate uses administrative cost data of unverified precision and excludes staff time spent on the improvement project itself, which was substantial and unpriced.

5.6. Implications for Research and Policy

For research, the most useful next step is not another single-site case study. It is a multi-site study using a standardised TAT definition and a common station taxonomy, which would permit the field to distinguish genuinely heterogeneous baseline dysfunction from inconsistent measurement, currently a plausible explanation for the very wide range of reported effect sizes. Longitudinal follow-up beyond twelve months is also scarce; the sustainment literature in LMIC settings is thinner than the implementation literature (Mazzocato *et al*., 2010; Radnor *et al*., 2012), and the drift observed here over fourteen weeks suggests that the interesting question is decay, not adoption. A further question follows directly: whether gains of this kind scale across a network of facilities rather than a single site (Eyetsemitan *et al*., 2020).

For policy, the finding that a binding constraint arose from an internal control policy has implications beyond pharmacy. Facilities should be required to conduct bottleneck analysis before submitting establishment increase requests, and internal control policies with physical layout implications should carry review dates.

5.7. Transferability of The Finding Across Domains

The claim that a constraint can be created by an obsolete control, then persist because nobody owns the question of whether it is still needed, is not specific to pharmacy or to healthcare. It appears in the internal audit literature as the problem of controls that outlive the risk they were written against (Akomolafe & Agu, 2018, 2019a), and in public sector financial management as the substitution of automated reconciliation routines for manual segregation of duties (Dogbatsey *et al*., 2019). The practical implication is that the diagnostic question this study asks, namely when a constraining policy was written and whether its original justification still holds, generalises further than the intervention does.

A second transferable element is the treatment of the dispensing shelf as an inventory positioning problem rather than a storage problem. The relationship between stock availability, retrieval time, and operational uptime is well established in asset-intensive industry (Okonkwo *et al*., 2018b, 2021a), and the materials readiness concept translates directly: a medicine that is present but unfindable is operationally equivalent to a medicine that is absent.

5.8. Measurement, Data Quality, And the Demand Signal

The weakest data in this study were not the time stamps, which were verified by gauge repeatability and reproducibility analysis, but the consumption history used to set reorder points and the voluntary incident log used for the error outcome.

On the first, the underlying difficulty is that public facilities in this setting are supplied by allocation and report by allocation, so consumption data must be reconstructed rather than read (Yadav, 2015). Predictive replenishment methods assume a demand series that most such facilities do not maintain (Aifuwa *et al*., 2020; Tonoyan *et al*., 2021a), and the visibility and vendor evaluation apparatus described in the procurement literature presupposes a data layer the national system has not yet built (Ahiaeke Patrick *et al*., 2021; Ilodigwe & Adesemoye, 2021; Nnabueze *et al*., 2021). Facility-level pull systems have a modest but real upstream benefit here, since they generate consumption records as a by-product.

On the second, the industrial safety literature is unambiguous that voluntary reporting measures reporting behaviour as much as it measures events (Arumosoye & Obriki, 2019; Obogo *et al*., 2021a), which is why the error reduction reported in Table 6 is the weakest claim in this paper. A replication should use a fixed-denominator audit of dispensed prescriptions rather than an incident log (Obogo *et al*., 2020a), and should adopt the prevention-oriented investigation logic that treats each event as information about the system rather than about the individual (Obogo *et al*., 2021b; Obriki & Arumosoye, 2020).

5.9. Workforce, Capability, And the Sustainment Problem

The drift observed over the fourteen-week control period is consistent with a broad finding across the improvement literature: adoption is easier than maintenance, and maintenance depends on capability and ownership rather than on the elegance of the original design (Radnor *et al*., 2012).

Three mechanisms are relevant. First, documented standard work is what survives staff turnover, which in this department was substantial, and the discipline of converting an external requirement into a written internal procedure is itself a skill (Eyetsemitan *et al*., 2021). Second, routine management presence on the floor sustains a standard that written documentation alone does not, a relationship established more clearly in industrial safety than in healthcare quality improvement (Obriki & Arumosoye, 2019, 2021), and leadership behaviour is the strongest single predictor of whether a new practice becomes normal (Obogo *et al*., 2019a). Third, sustainment requires a named owner with authority across the boundary that the process crosses, since the countermeasure that decayed fastest here was the one dependent on departments outside pharmacy control (Arumosoye & Obriki, 2020; Eyetsemitan *et al*., 2020).

The broader capability argument is that improvement in constrained systems is limited by organisational readiness rather than by access to methods, and that investment in workforce training is therefore not a soft complement to operational change but a precondition for it (Orise & Niniola, 2020).

6. Conclusion

In a 520-bed public tertiary hospital in a lower-middle-income setting, the dominant constraint on outpatient pharmacy throughput during 2021 was structural rather than a shortage of pharmacists. A DMAIC-structured Lean Six Sigma intervention reduced mean prescription turnaround time from 76.3 to 41.7 minutes, raised process cycle efficiency from 15.9% to 27.3%, lifted process sigma from 0.94 to 2.79, and cut fast-mover stockouts from 18.6% to 6.9%, at a direct cost of approximately USD 6,400 with a payback period under four months. Roughly three fifths of the improvement traced to a single layout change: moving a billing terminal into the dispensing area and thereby eliminating a second patient queue.

The wider claim this study supports is narrow but useful. Lean Six Sigma does not require digital infrastructure, capital budget, or additional establishment to produce material gains in a resource-constrained pharmacy, and the analytical value of the method lies chiefly in its refusal to accept the intuitive diagnosis. The main risk to such projects is not staff resistance during implementation but quiet erosion afterwards, which places the weight of long-term success on the control phase, the phase most often abbreviated in both practice and publication.

Declarations

Ethics approval and consent to participate: Approved by the [Institution] Health Research Ethics Committee, protocol [XXX/2021/XXX]. Verbal informed consent was obtained from all survey participants.

Consent for publication: Not applicable; no individually identifiable data are reported.

Availability of data and materials: The de-identified dataset supporting the conclusions is available from the corresponding author on reasonable request.

Competing interests: The authors declare no competing interests.

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Authors' contributions: [Specify per ICMJE criteria: conception and design; data acquisition; analysis and interpretation; drafting; critical revision; final approval.]

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Appendix A: Data collection instrument (time study sheet)

Field	Format	Notes
Observation ID	Sequential	Unique per prescription
Date and session	Date; AM/PM	Session boundary at 13:00
T0 Ticket issued	hh:mm	Start of measured interval
T1 Window presentation	hh:mm	Station 1 boundary
T2 Screening complete	hh:mm	Station 2 boundary
T3 Departure to cashier	hh:mm	Baseline period only
T4 Return from cashier	hh:mm	Baseline period only
T5 Picking complete	hh:mm	Station 5 boundary
T6 Handover to patient	hh:mm	End of measured interval
Line items	Integer	Count of distinct medicines
Stockout event	Y/N; item code	Any line item unavailable
Prescription defect	Y/N; type	Illegible, incomplete, or clarification required
Exception notes	Free text	Prescriber callback, substitution, partial fill

Appendix B. Five-why analysis of the dominant root cause

Problem statement. Patients wait a mean of 33.7 minutes in transit to and queueing at the cashier station.

1. **Why?** Because billing is performed at a station 85 metres from the pharmacy, in a separate wing.
2. **Why?** Because hospital policy requires that cash handling be physically separated from stock handling.
3. **Why?** Because a 2014 internal audit identified a reconciliation risk where the same officer both collected payment and released stock.
4. **Why?** Because at that time payment records were kept manually and could not be reconciled independently against dispensing records.
5. **Why is this still the arrangement?** Because the policy was never revisited after the 2018 introduction of an electronic billing system that produces an independently auditable transaction log.

Countermeasure implication: The control objective (independent reconciliation) can be satisfied by a system-generated daily reconciliation report rather than by physical separation. Physical separation is therefore removable without loss of control integrity.

Appendix C: 5S audit checklist (25-point, weekly)

Dimension	Items	Max score
Sort	No expired or obsolete stock on active shelves; no non-pharmacy items in dispensing area; unused equipment removed	5
Set in order	Fixed-location labels intact; fast movers in designated zone; picking path unobstructed; bin cards present	5
Shine	Shelves and counters clean; refrigerator temperature log current; waste bins emptied	5
Standardise	Standard work instruction posted at each window; labelling format consistent; tallman lettering intact on LASA pairs	5
Sustain	Previous week's audit actions closed; TAT board updated for every hour of previous day; kanban bins returned to correct positions	5
Total		25

Reaction rule: a score below 20 triggers a departmental re-set within 48 hours, led by the chief technician, with the corrective action recorded in the quality log.

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