

Original Research

Received 27 May 2026

Revised 25 July 2026

Accepted 02 August 2026

Natural Resources for Human
Health 2026, Vol. 6 (14s): 1167–1187

KEYWORDS:

Lean Six Sigma; DMAIC;
operating room; turnover time;
healthcare operations; role
attribution; process capability;
systematic literature review

Who Improves the Operating Room? Professional Role Attribution and Process- Metric Reporting in Lean Six Sigma Perioperative Interventions: A Systematic Literature Review

¹María José Lozano Flores, ²Arnold Rafael Montt Torres, ³Ana
Luisa Arzuaga Arzuaga, ⁴María Carolina Araujo Arzuaga,
⁵Michelt Mariuxi Zabaleta Heredia

¹Universidad Popular del Cesar, Valledupar, Colombia
Email: mariajlozano@unicesar.edu.co

²Universidad Popular del Cesar, Valledupar, Colombia
Email: amontt@unicesar.edu.co

³Universidad Popular del Cesar, Valledupar, Colombia
Email: analarzuaga@unicesar.edu.co

⁴Universidad Popular del Cesar, Valledupar, Colombia
Email: mariaaraujo@unicesar.edu.co

⁵Universidad Popular del Cesar, Valledupar, Colombia
Email: micheltzabaleta@unicesar.edu.co

ABSTRACT: Purpose — Lean and Lean Six Sigma (LSS) are widely reported to improve operating room (OR) efficiency, yet it remains unclear which professional groups drive these gains and whether the interventions report the process metrics that define the Six Sigma method. This review examines the effect of Lean, Six Sigma and LSS interventions on OR turnover time and OR utilization, and systematically audits how the literature attributes implementation leadership and reports process capability metrics.

Design/Methodology/Approach — A systematic literature review following PRISMA 2020 reporting conventions. A semantic search of 138 million records was executed through twenty structured queries, returning 4,000 records; 1,357 duplicates were removed and 2,643 abstracts were screened against four eligibility criteria. Full-text screening applied three additional criteria. Twelve studies published between 2013 and 2024 met all criteria and entered structured extraction across twenty fields, including leadership attribution and process-metric reporting. Heterogeneity in outcome definitions precluded meta-analysis; synthesis follows the SWiM guideline.

Findings — Six studies reported measured pre-post turnover time, with reductions ranging from 0.2 minutes (−1.2%) to 23 minutes (−62.2%). Reduction magnitude tracked intervention breadth and baseline level rather than the specific Lean tool applied. OR utilization was reported in only three studies, in conflicting directions, with no statistical testing. Three reporting gaps were pervasive: no study reported process sigma or defects per million opportunities (0/12); eight of twelve attributed leadership to a multidisciplinary team without identifying a lead, and none was led by perioperative nursing or surgical technologists/scrub practitioners; and no study compared outcomes by professional role. Scrub practitioners appeared as team members in six studies, as affected staff in two, and were absent from four.

Research Limitations/Implications — Full text was unavailable for 205 of 251 otherwise-eligible records, which constrains the evidence base and may bias it toward open-access reporting. All included studies were observational and ten lacked concurrent

controls. The absence of sigma-level reporting in studies self-labelled as Six Sigma or DMAIC raises a construct-validity question for the field: interventions are labelled by method but evaluated by outcome proxies unrelated to process capability.

Practical Implications — Organisations should specify and record role-level accountability when designing perioperative LSS projects, and should harmonise turnover-time definitions before benchmarking. The findings bear directly on task design in resource-constrained health systems, where reallocating turnover activities to surgical instrumentation professionals is a plausible but entirely untested lever.

Originality/Value — This is, to the authors' knowledge, the first review to treat leadership attribution and process-metric reporting in perioperative LSS as objects of systematic audit rather than as background description. It documents that the professional group most directly engaged in OR turnover activity has never led a published improvement intervention in this literature.

INTRODUCTION

Operating rooms concentrate cost and constrain throughput in almost every hospital. The OR accounts for approximately 35–40 per cent of hospital costs and 60–70 per cent of hospital revenue (Healey et al., 2015), and it is simultaneously among the units most sensitive to small process failures: a delayed first case, an incomplete instrument tray, or an unclear handover propagates through an entire day's schedule.

The financial weight of OR time is well established but poorly standardised. Childers and Maggard-Gibbons (2018) derived a widely cited benchmark of US\$36–37 per minute from Californian hospital disclosure data; the same series updated to fiscal year 2022 gives US\$57.71 per minute, a 54 per cent increase (Ashrafi et al., 2026). Across the wider literature, published estimates of one minute of OR time range from US\$7 to US\$113 depending on costing method (Christou et al., 2022), and a consensus exercise across fourteen novel estimates returned a mean of US\$46.04 with a standard deviation of US\$32.31 (Smith et al., 2022). Any claim about the financial value of released OR minutes therefore depends heavily on the denominator chosen.

This combination of cost intensity and process fragility has made perioperative services a natural target for the transfer of manufacturing-derived improvement methods into healthcare. Lean, Six Sigma and their combination as Lean Six Sigma (LSS) now constitute the dominant vocabulary of that transfer, and the body of empirical work is substantial: systematic reviews have been published on Six Sigma in healthcare generally (Antony et al., 2018; Niñerola et al., 2020), on Lean and Six Sigma in acute care (Deblois and Lepanto, 2016), on empirical LSS research (Henrique and Godinho Filho, 2020), on motivations, benefits, challenges and critical success factors (McDermott et al., 2022a, 2022b), on implementation case studies (Samanta et al., 2022), on Lean management in hospitals (Mousavi Isfahani et al., 2019; Wang et al., 2025), and specifically on Lean and Six Sigma in surgery (Mason et al., 2015).

The headline message of this literature is broadly favourable, but not uniformly so. Mason et al. (2015) found that 88 per cent of 23 included surgical studies demonstrated improvement while noting high levels of systematic bias and imprecision. Moraros et al. (2016), assessing Lean interventions independently, reported no statistically significant association with patient satisfaction or health outcomes, a negative association with financial costs and worker satisfaction, and only inconsistent benefits on process outcomes. Glasgow et al. (2010) found that of 47 included studies only 15 reported any follow-up data and only three reported follow-up beyond two years; Samanta et al. (2022) similarly found post-intervention data up to three years in only 20 per cent of articles. Turnover time is the single most studied metric of OR efficiency (Madura et al., 2025), yet a dedicated systematic review of turnover interventions concluded that methodologies vary so widely that comparison is difficult (Cohen et al., 2023).

What this literature reports much less consistently is how the improvement was produced and by whom. Two omissions are particularly consequential for a field organised around methodological discipline.

The first concerns process capability. Six Sigma is constituted by the measurement of variation against customer specification, operationalised through process sigma levels, defects per million opportunities (DPMO) or capability indices. A study that labels itself a DMAIC project but evaluates success solely through a mean time reduction has adopted the method's structure

without its measurement logic. Whether this is widespread, and whether it matters, is an empirical question that has not been asked systematically of the perioperative literature.

The second concerns role attribution. Perioperative work is distributed across surgeons, anaesthetists, perioperative nurses, surgical technologists and instrumentation professionals, sterile processing staff, porters and housekeeping. Turnover — the interval this literature most often measures — is executed largely by the latter groups, and the empirical evidence increasingly identifies their tasks as the binding constraint: in an artificial-intelligence-based observational study of 53 turnovers, instrument setup duration emerged as the single greatest determinant of turnover variability, adding 2.7 minutes per additional instrument tray (Smit et al., 2026). Yet improvement projects are typically reported at the level of “the team”, which makes it impossible to identify which forms of professional expertise or authority are doing the causal work.

This review therefore pursues a dual objective. It synthesises the measured effects of Lean, Six Sigma and LSS interventions on OR turnover time and OR utilization. And it audits the same body of studies for how they attribute implementation leadership and whether they report the process metrics their own methodological labels imply. The second objective is treated not as a limitation of the evidence but as a finding about the state of the field.

Research questions

- *RQ1.* What magnitude of change in OR turnover time and OR utilization is reported following Lean, Six Sigma or LSS interventions in perioperative services, and what accounts for variation in that magnitude?
- *RQ2.* Which professional groups are reported as leading or implementing these interventions, and do reported outcomes differ by leading role?
- *RQ3.* To what extent does the perioperative LSS literature report process capability metrics consistent with its own methodological claims?

2. THEORETICAL BACKGROUND

2.1 Lean, Six Sigma and their combination in perioperative services

Lean and Six Sigma address different failure modes. Lean targets non-value-adding activity — waiting, transport, motion, over-processing — through value stream mapping, kaizen events, single-minute exchange of die (SMED) and standardised work. Six Sigma targets variation, using the Define-Measure-Analyze-Improve-Control (DMAIC) cycle to move a process toward specification with quantified capability. LSS combines both, and reviews of healthcare applications consistently observe that the combination is invoked loosely, with DMAIC language applied to what are structurally kaizen interventions (Antony et al., 2018; Henrique and Godinho Filho, 2020; Samanta et al., 2022).

Reviews also converge on a set of recurring weaknesses. Study designs are predominantly uncontrolled before-after comparisons (Glasgow et al., 2010; Mason et al., 2015; Mousli et al., 2025); interventions concentrate on management rather than clinical processes (Rathi et al., 2021); evidence from developing economies is sparse (Rathi et al., 2021; Mousli et al., 2025); economic evaluation is largely absent (Mousli et al., 2025); and sustainability beyond twelve months is rarely documented (Glasgow et al., 2010; Samanta et al., 2022). Deblois and Lepanto (2016), in a review of reviews, judged the overall quality of evidence poor to fair and observed that Lean and Six Sigma appear better adapted to settings where processes involve a linear sequence of events — a description that fits OR turnover precisely.

The perioperative application has a clear technical logic. Turnover is a changeover problem, and SMED — developed for die changes in stamping presses — maps onto it almost directly: separate internal from external setup, convert internal to external, streamline what remains. Parallel processing of anaesthesia induction, advance tray preparation and pre-positioning of equipment are all instances of converting internal setup to external setup. Comparable logic underlies the motor-racing pit-stop analogy applied to robotic turnover by Souders et al. (2017), who reduced mean total turnover from 99.2 to 53.2 minutes through briefings, role definition, task allocation and task sequencing. Systematic mapping of turnover determinants identifies parallel processing, team dynamics and a “focused factory” approach as the most impactful domains (Madura et al., 2025), and human factors analyses reach the same conclusion through a different route, identifying clear designation of roles and simultaneous task completion as the effective components (Cohen et al., 2022).

2.2 Role attribution and task design as an operations problem

Operations management has long recognised that process improvement outcomes depend on who holds process knowledge and who holds the authority to change the process. The healthcare evidence on sustaining Lean is unusually explicit on this point. Kunnen et al. (2023), synthesising 24 studies on the sustainment of Lean management, identify assigning greater decision-making responsibility to employees and appointing local change agents among the key facilitators, and omitting staff involvement during implementation among the key barriers. Cadeddu et al. (2023) map employee-driven innovation in health organisations and find that frontline clinical and non-clinical staff generate improvement ideas that top-down programmes systematically miss. In a structural model of 384 hospital respondents, Ahmed et al. (2025) found employee involvement to have a larger effect on patient safety quality than either leadership or LSS practice itself, with leadership acting only indirectly through involvement. Behavioural work in adjacent service settings reaches a parallel conclusion: structured quality methods do not influence frontline capability directly but operate through empowerment and continuous improvement behaviour (Lee et al., 2025).

The converse is also documented. Robert et al. (2019), tracing a decade of the Productive Ward programme across six English hospitals, found that resource constraints and a managerial preference for standardisation produced a progressive shift away from the original vision of empowering ward staff towards implementation short cuts, with consequences for assimilation into routine practice. Studies of role structure in improvement work find that different organisational levels play distinct and non-substitutable parts (Kirchner et al., 2012; Gagnon et al., 2024), and that frontline staff and managers systematically diverge in what they perceive an initiative to have achieved (Parand et al., 2011).

Most directly relevant, Cranley et al. (2018) found that care aides — the unregulated cadre executing much of the hands-on work in long-term care — reported significantly less involvement in improvement activity, less empowerment and lower satisfaction than regulated care providers in the same facilities. The structural position of the surgical instrumentation professional in the OR is analogous.

Perioperative turnover is a case where the separation of process knowledge from change authority is structural. The staff who execute turnover tasks — scrub practitioners, surgical technologists, instrumentation professionals, sterile processing and housekeeping — generally hold neither project authority nor publication authorship. This matters because the competencies at stake are formally defined and exclusive: von Vogelsang et al. (2019), analysing legal statutes alongside the scientific literature, conclude that the specialist operating theatre nurse is the only healthcare professional with the competence to be responsible for asepsis, instrumentation, infection and complication control during the surgical procedure, and that no other profession holds the formal education or skills to perform that care.

A striking parallel exists in the literature on these professionals' own capabilities. Mitchell and Flin (2008), reviewing the non-technical skills of the operating theatre scrub nurse, found that of 424 retrieved publications only 13 presented relevant data, and that none of the reviewed papers examined leadership or decision-making by scrub nurses. Later work established that these skills do exist and are more extensive than previously identified, with independent decision-making and leadership emerging as novel categories in a Delphi study of 106 operating room nurses (Sirevåg et al., 2021). Performance is shaped by team familiarity and patient acuity (Kang et al., 2015), facilitated by role awareness and impeded by hierarchical culture (Chen et al., 2026), and constrained by organisational silence, which is a significant negative predictor of perioperative competence (Kim et al., 2026). Two independent literatures — improvement science and perioperative nursing — have thus each omitted the leadership dimension of the same professional group.

If improvement outcomes depend on aligning process knowledge with change authority, then the professional composition of the leading coalition is a theoretically motivated moderator, not a descriptive detail. This review tests whether the literature permits that moderator to be examined at all.

2.3 Definitional heterogeneity and reporting quality as prior constraints

Two prior constraints shape what any synthesis of this literature can conclude.

The first is definitional. Fixler and Wright (2013a) identified inconsistent indicator definitions as the central obstacle to external benchmarking of OR performance, noting that only uniform data and indicator definitions permit hospitals to benchmark and share learning. In a subsequent exchange they observed that even the Association of Anesthesia Clinical Directors Procedural Times Glossary — which defines turnover time as the interval from prior patient out of room to succeeding patient in room

for sequentially scheduled cases — leaves unresolved how to treat delays unrelated to room cleaning and preparation, and that hospital practice varies materially as a result (Fixler and Wright, 2013b). Human factors work reaches the same conclusion from the measurement side, describing turnover time as under-researched and inconsistently operationalised (Schock et al., 2019), and demonstrating that segmenting the interval into task-based submeasures is what makes accountability assignable (Goldhaber et al., 2023). Specialty-specific normalisation has been proposed precisely because unadjusted OR-wide averages misrepresent performance (Zhang et al., 2026).

The second is reporting quality. SQUIRE 2.0 provides the reference standard for reporting systematic improvement efforts, emphasising the use of formal and informal theory, the context of the work, and the study of the intervention (Ogrinc et al., 2015; Goodman et al., 2016). Adherence, however, is poor and has not visibly improved: a before-and-after evaluation found no significant change in the completeness of reporting following publication of the original guidelines (Howell et al., 2015). Domain-specific audits confirm the pattern — mean adherence to 22 of 31 modified SQUIRE items in neonatology (Hu et al., 2021), all 18 criteria met by only 9 per cent of breast reconstruction studies (Pereira et al., 2022) and 14 per cent of plastic surgery studies (Pereira et al., 2023), with the lowest scores concentrated in interpretation, costs, strategic trade-offs, sustainability and potential for spread. Reporting-quality audits of improvement literature are therefore an established genre; the present review extends it to perioperative LSS and adds two dimensions not previously audited, namely role attribution and process capability reporting.

2.4 Task redistribution in resource-constrained surgical systems

The practical stake in role attribution is highest where surgical capacity is scarcest. Task shifting and task sharing — redistributing responsibilities to cadres with less or more narrowly tailored training — is an established strategy for addressing workforce shortages and skill-mix imbalance (Fulton et al., 2011). In surgery it is widely practised: non-surgeon providers have been documented performing 46 types of procedure across eight disciplines in 41 low- and middle-income countries (Hoyler et al., 2015), with task sharing present in the anaesthetic workforce of 39 low-resource countries and in the surgical workforce of 13 (Ashengo et al., 2017). Syntheses of clinical outcomes find non-specialists safe for high-volume, lower-complexity operations (Bognini et al., 2023), and economic appraisals find task shifting cost-effective, lowering total cost and increasing coverage without significant outcome differences (Okon et al., 2025). The strategy is no longer confined to low-income settings: advanced practice providers are being integrated into surgical teams in high-income systems, and the open question is whether that redistribution is evidence-driven or haphazard (Modi et al., 2025).

Two conditions recur in this literature as prerequisites for safe redistribution: clearly defined scopes of practice with associated competencies, and established supervision and quality assurance mechanisms (Ashengo et al., 2017; Modi et al., 2025). Health worker perspectives add a third — preparatory training and ongoing access to resources (Coales et al., 2023). Redistributing perioperative turnover tasks toward instrumentation professionals is a candidate application of exactly this logic, since the relevant competencies are already formally held (von Vogelsang et al., 2019) and the relevant tasks are already the dominant source of turnover variability (Smit et al., 2026). Whether it works is the question this review finds unasked.

3. METHODOLOGY

3.1 Review design

The review follows PRISMA 2020 reporting conventions, adapted to the conventions of management and operations research. It was conducted as a systematic literature review rather than a Cochrane-style intervention review, and synthesis follows the SWiM (Synthesis Without Meta-analysis) guideline because outcome definitions proved too heterogeneous to pool.

3.2 Search strategy

A semantic search was executed through the Elicit research platform, which indexes over 138 million academic records including Semantic Scholar and OpenAlex. Twenty structured queries were run, spanning: LSS and DMAIC in operating rooms; turnover, changeover and non-operative time; theatre utilisation; first-case on-time starts; value stream mapping and kaizen; process sigma and DPMO; nursing-led and multidisciplinary perioperative improvement; surgical technologist and scrub practitioner roles; case cancellation; sterile processing and tray optimisation; implementation in low- and middle-income countries; and Latin American and Colombian surgical services. The complete query list is provided in Appendix A. No date or language restriction was applied at search stage.

The searches returned 4,000 records. The 2,643 records most relevant to the review question were retrieved for screening after removal of 1,357 duplicates. Semantic retrieval was selected for breadth of coverage across the management, engineering and clinical literatures in which this work is dispersed. It is not exactly reproducible, since retrieval indices and models change over time, and this is stated as a limitation in Section 7.

3.3 Eligibility criteria

Abstract-stage criteria, all of which had to be met:

1. **Perioperative surgical setting** — hospital operating room, operating theatre, surgical suite, day surgery unit or ambulatory surgery centre.
2. **Lean or Six Sigma intervention** — an actually implemented Lean, Six Sigma or LSS intervention, including DMAIC, value stream mapping, kaizen or explicitly equivalent structured continuous improvement. Passing mentions, proposals without implementation and generic quality improvement were excluded.
3. **Empirical quantitative data** — measured outcome data from a real implementation. Reviews, editorials, commentaries, protocols, abstracts without results and simulation-only modelling were excluded.
4. **Relevant efficiency outcome** — at least one measured OR efficiency outcome: turnover time, changeover time, non-operative time, utilisation rate, first-case on-time start rate, or throughput per session.

Full-text criteria, applied additionally:

5. **Extractable effect data** — numeric baseline and post-intervention values sufficient to compute or approximate an effect size.
6. **Identifiable implementation team** — some information on who designed, led or implemented the intervention. Records with vague team description were retained, since non-reporting was itself an object of study.
7. **Full text accessible in English or Spanish.**

3.4 Screening and selection

251 of 2,643 records passed abstract screening. Primary exclusion reasons were: Lean or Six Sigma intervention absent ($n = 1,384$), non-perioperative setting ($n = 677$), no empirical quantitative data ($n = 188$), and no relevant efficiency outcome ($n = 143$).

Twelve of 251 records passed full-text screening. Exclusion reasons were: **full text not available ($n = 205$)**, effect data not extractable ($n = 15$), no empirical quantitative data ($n = 8$), non-perioperative setting ($n = 5$), intervention not Lean or Six Sigma ($n = 4$), implementation team wholly unidentifiable ($n = 1$), and language ($n = 1$).

The dominance of full-text unavailability is material and is treated as a limitation in Section 7 rather than as a neutral procedural detail: 82 per cent of attrition at full-text stage was an access failure, not an eligibility failure.

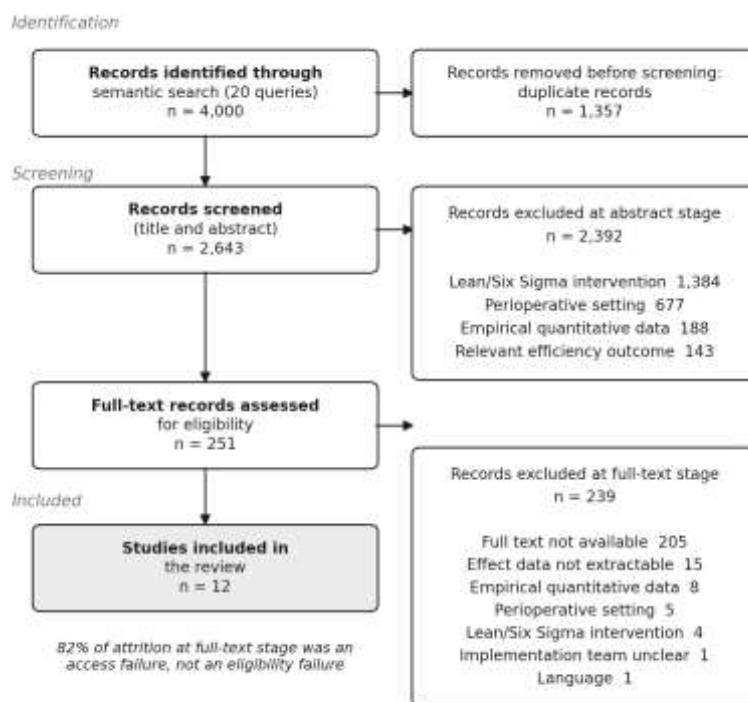


Figure 1. Study selection flow

3.5 Data extraction

Twenty fields were extracted per study: country; World Bank income group; study design; surgical specialty and facility type; sample size; intervention type and components; intervention and follow-up duration; baseline and post-intervention values with dispersion for turnover time and utilisation; statistical testing; professional group leading the intervention; degree of surgical technologist or scrub involvement; sigma level or DPMO; safety outcomes; economic outcomes; validity threats; and author-stated limitations. Extraction prompts are reproduced in Appendix B.

Leadership attribution was coded from explicit statements about project leadership, champions or team composition in the text, not from authorship, which is an unreliable proxy for who conducted the work.

3.6 Use of AI-assisted screening and extraction

Screening and structured extraction were performed using a large language model applying the pre-specified criteria and extraction prompts. All extracted numeric values reported in Tables II, III, IV and VI were subsequently verified against the source publications by the authors, who accept responsibility for their accuracy. Decisions to include or exclude at full-text stage were reviewed by the authors against the recorded supporting quotations.

4. FINDINGS

4.1 Characteristics of included studies

Twelve studies published between 2013 and 2024 met all criteria. Nine were conducted in high-income countries — five in the United States, one each in Switzerland, the United Kingdom, Spain and New Zealand. One was conducted in Brazil, an upper-middle-income setting. Two reported neither country nor income setting.

No study was conducted in Colombia, and no study in any Spanish-speaking Latin American health system met the inclusion criteria. The single Latin American study modelled hypothetical improvement scenarios without implementing them. This is consistent with the geographic concentration observed in prior reviews (Niñerola et al., 2020; Rathi et al., 2021) and with the explicit call to extend LSS research to low- and middle-income settings (Mousli et al., 2025).

All twelve used observational designs. Two incorporated a concurrent control group; the remainder relied on uncontrolled pre-post comparison or exploratory designs. No randomised trials were identified. Intervention methodologies comprised pure Lean approaches (seven studies), LSS or DMAIC-based approaches (four), and one combining Lean with Six Sigma tools without labelling the approach DMAIC. Specialties spanned general, orthopaedic, vascular, spine, gynaecologic, thoracic, bariatric and cataract surgery, GI endoscopy and multi-specialty suites. Facilities ranged from academic centres with more than 50 ORs to community hospitals with fewer than seven suites. Sample sizes ranged from 30 surgical cases to more than 38,000 patients annually.

Table I. Characteristics of the twelve included studies

Study	Country	Design	Specialty	Facility	Method	Follow-up
Cerfolio et al. (2019)	United States	Controlled before-after	General (minimally invasive abdominal)	Academic health centre, NYC	Lean, VSM	Not reported
Amati et al. (2022)	Switzerland	Uncontrolled pre-post / action research	Gynaecologic and general	Public regional hospital, 5 ORs	Lean, SMED	3 months
Souza et al. (2020)	Brazil	Exploratory / descriptive	Multiple (15 specialties)	Large university hospital, 7 ORs	Lean (ORE indicator)	None
Claudio et al. (2021)	United States	Uncontrolled pre-post	Orthopaedic, expanded to all	Acute care hospital, 86 beds	Lean, kaizen, VSM	4 weeks
Warner et al. (2013)	United States	Interrupted time series	Vascular	400-bed academic medical centre	LSS DMAIC, VSM	12 months
Lin et al. (2022)	Not reported	Uncontrolled pre-post	General (transport process)	Not specified	Lean, VSM, A3	Not reported
New et al. (2016)	United Kingdom	Controlled before-after / ITS	Trauma orthopaedics	UK teaching hospital	Lean, kaizen	6 months
Sales et al. (2023)	Spain	Uncontrolled pre-post	Complex general surgery	University hospital, 51 ORs	Lean, kaizen, VSM	~48 months
Ammanuel et al. (2020)	United States	Uncontrolled pre-post	Spine / neurosurgery	Academic spine practice	Lean Six Sigma	Not reported
Kidambi et al. (2024)	United States	Uncontrolled pre-post	GI endoscopy	Hospital-based ambulatory surgery centre	Lean	Not reported

Study	Country	Design	Specialty	Facility	Method	Follow-up
Sanchez et al. (2023)	Not reported	Uncontrolled pre-post	Bariatric and thoracic (robotic)	Single centre, not specified	LSS DMAIC	Not reported
Chiesa et al. (2024)	New Zealand	Uncontrolled pre-post	Ophthalmology (cataract)	District secondary service	Lean Six Sigma	~35 months

VSM = value stream mapping; SMED = single-minute exchange of die; ORE = operating room effectiveness; ITS = interrupted time series.

4.2 Effects on OR turnover time (RQ1)

Seven studies reported turnover time; six reported measured pre-post values and one modelled hypothetical setup reductions only.

Table II. Turnover time outcomes

Study	Turnover definition	Baseline (min)	Post (min)	Change	%	p	n (turnovers)
Cerfolio (2019)	Wheels out to wheels in	Median 37 (26–167)	Median 14 (10–45)	–23	–62.2	<0.0001	69 pre; 35 post
Sales (2023)	Exit to next entry and prep	38	16	–22	–57.9	Not tested	Not reported
Amati (2022)	Last stitch to incision	Mean 62 (gyn); 64 (gen)	41; 48	–17; –15	≥25 avg	Not tested	Not reported
Sanchez (2023)	Wheels out to wheels in	Mean 35.6 (SD 8.1)	Mean 30.09 (SD 9.7)	–5.5	–15.6	<0.05; 0.09 thoracic	53 pre; 93 post
Claudio (2021)	Patient exit to next entry (cleaning only)	Mean 14.00 (SD 5.22)	Mean 11.80 (SD 1.93)	–2.2	–15.7	0.001; 0.018	12 pre; 692 all-surgery
Kidambi (2024)	Wheels out to wheels in	Mean 16.6 (SD 7.9)	Mean 16.4 (SD 8.3)	–0.2	–1.2	0.84	Not reported
Souza (2020)	Setup (cleaning / prep)	Not reported	Hypothetical only	–5 modelled	—	—	—

Definitions are not equivalent across studies and absolute values are therefore not directly comparable.

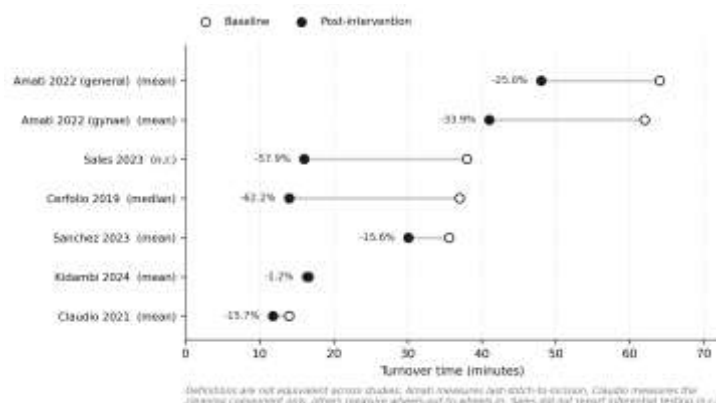


Figure 2. Reported turnover time before and after intervention

Reductions spanned essentially zero to 62 per cent, a range consistent with the 1 to 45 per cent span reported across the broader turnover intervention literature (Cohen et al., 2023) and with the 6 to 22 per cent OR-time reductions found for standardisation interventions generally (Schoeneberg et al., 2023). Four studies achieved statistically significant improvement, two performed no inferential testing, and one found no change.

Three contextual factors account for most of this dispersion, and none of them is the specific Lean tool employed.

Intervention breadth. The two largest absolute reductions — Cerfolio et al. (–23 min) and Sales et al. (–22 min) — both implemented comprehensive multi-component redesign spanning the whole perioperative workflow, including institutional policy change, dedicated staffing and parallelised tasks across professional groups. Narrowly scoped interventions produced proportionally smaller effects: standardised cleaning alone yielded –2.2 minutes, tray optimisation with parallel robotic setup –5.5 minutes. The pattern is roughly dose-responsive in intervention breadth, and it corroborates the finding that process redesign bundles developed from prospective work-system analysis outperform single targeted changes (Cohen et al., 2023; Madura et al., 2025).

Baseline level and ceiling effects. Studies starting from higher baselines achieved larger absolute reductions. Cerfolio et al. began at a median of 37 minutes and Sales et al. at 38; Kidambi et al. began at 16.6 minutes and achieved no measurable change, with the authors themselves acknowledging a probable ceiling. Below roughly 15 minutes, further compression appears to require either resource addition or redefinition of the interval measured.

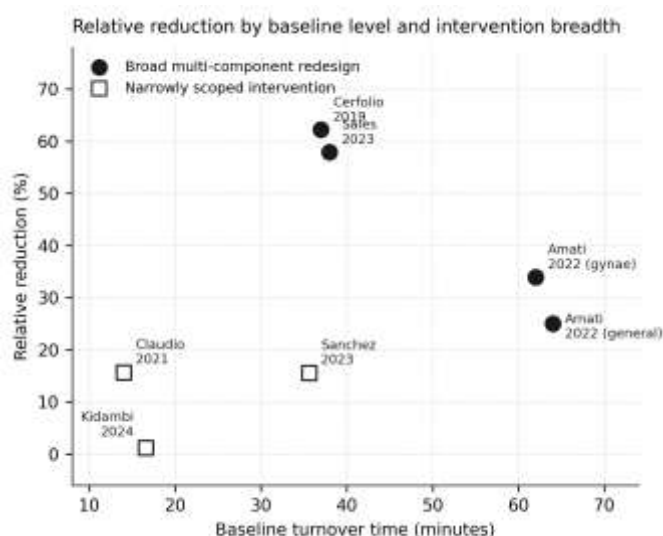


Figure 3. Relative reduction by baseline level and intervention breadth

Definitional heterogeneity. Definitions ranged from wheels-out-to-wheels-in to last-stitch-to-incision, the latter encompassing anaesthesia induction and patient positioning. Amati et al. reported a 62–64 minute baseline under the broader definition; Claudio et al. reported 14 minutes for the cleaning component alone. These are not comparable quantities, and the problem is a known structural feature of OR performance measurement rather than an artefact of this sample (Fixler and Wright, 2013a, 2013b; Schock et al., 2019).

Cross-study comparison of absolute turnover reductions is unsound without definitional harmonisation, and this — not sampling variation — is the principal barrier to quantitative synthesis in this literature.

4.3 Effects on OR utilization (RQ1)

Only three studies reported utilisation, using three different constructs, in two directions, with no statistical testing in any of them.

Table III. Utilization outcomes

Study	Metric	Baseline	Post	Change	Testing
Sales (2023)	Surgical occupation	73%	84%	+11 pp	None
Chiesa (2024)	Surgical session utilisation	95%	85%	–10 pp	None
Souza (2020)	ORE (availability × performance × quality)	57.3%	59.7–88.9% (modelled)	Not observed	None

Chiesa et al. reported a decline in session utilisation despite a 12 per cent rise in monthly cataract volume, attributed to COVID-19 cancellations and a shift toward wet-leased private theatres. This is instructive rather than anomalous: utilisation is a ratio, and external shocks that alter the capacity denominator can move it opposite to throughput. The same insensitivity has been observed at scale — participation in a national surgical benchmarking programme across 202 German departments produced no clear trend in raw utilisation and an increasing trend in turnover time (Pedron et al., 2017). Utilisation is therefore a poor standalone indicator of LSS effect unless the denominator is held stable or reported explicitly.

The evidence base on OR utilisation is insufficient to support any conclusion about the effect of LSS interventions.

4.4 Related efficiency outcomes

Table IV. Adjacent perioperative efficiency outcomes

Study	Outcome	Baseline	Post	Change	p
Warner (2013)	First-case on-time starts	39%	86% at 1 year	+47 pp	<0.001
Warner (2013)	Resident rounding time	70.0 min (SD 5.0)	47.2 min (SD 9.0)	–33%	Not reported
Kidambi (2024)	On-time starts	46.4%	69.9%	+23.5 pp	<0.0001
Kidambi (2024)	Total facility time	196.1 min (SD 41.7)	172.5 min (SD 38.7)	–23.6 min	<0.001
Ammanuel (2020)	Perioperative anaesthesia time	88.4 min (SD 4.7)	76.2 min (SD 3.2)	–12.2 min	0.04
Ammanuel (2020)	Total OR time	270.1 min (SD 14.6)	252.8 min (SD 14.1)	–17.3 min	0.55
Lin (2022)	Ward-to-OR transport time	53 min	20 min (median)	–62.3%	Not reported

Study	Outcome	Baseline	Post	Change	p
Sales (2023)	First-case start time	9:38 a.m.	8:27 a.m.	−71 min	Not reported
New (2016)	First-patient arrival time	Not quantified	20 min earlier	+20 min earlier	Not formally tested

Adjacent outcomes were more consistently positive. Warner et al. raised first-case on-time starts from 39 to 86 per cent, sustained at one year, the most robust sustained result in the review. Kidambi et al., despite a null turnover result, improved on-time starts from 46.4 to 69.9 per cent and total facility time by 23.6 minutes. Lin et al. reduced ward-to-OR transport from 53 to 20 minutes. Sales et al. advanced first-case start time by 71 minutes. This asymmetry matches the benchmarking evidence, in which first-case tardiness responded to measurement and feedback while turnover time did not (Pedron et al., 2017).

Two findings complicate the assumption that component gains aggregate. Ammanuel et al. reduced perioperative anaesthesia time by 12.2 minutes ($p = 0.04$) with no significant change in total OR time ($p = 0.55$). New et al. found that patients arriving 20 minutes earlier at the anaesthetic room produced no improvement in knife-to-skin time, because anaesthetic-room time expanded to fill the interval released.

Time removed from one process segment is not necessarily time recovered at system level — a straightforward instance of local optimisation without system constraint relief, and a caution for benchmarking on segment-level metrics.

4.5 Professional role attribution (RQ2)

Table V. Leadership attribution across the twelve included studies

Attribution	n	Studies
Multidisciplinary, no single lead	8	Cerfolio; Claudio; Souza; Lin; Ammanuel; Kidambi; Sanchez; Chiesa
Anaesthesiology-led	1	Amati
Industrial engineering / quality department-led	1	Warner
Surgeon-led	1	New
Hospital administration-led	1	Sales
Perioperative nursing-led	0	—
Surgical technologist / scrub / instrumentation-led	0	—

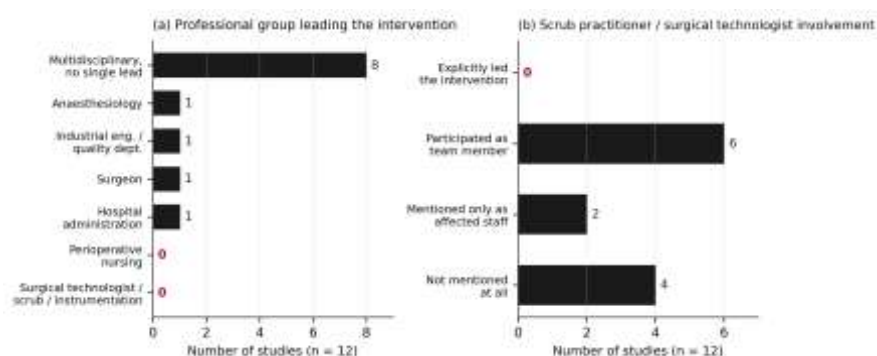


Figure 4. Leadership attribution and scrub practitioner involvement

Two-thirds of studies attributed leadership to an unspecified multidisciplinary team. No study compared outcomes by professional role. The four studies with an identified single lead offer only isolated observations: the anaesthesiology-led study achieved a reduction of at least 25 per cent, the surgeon-led study achieved no measurable efficiency improvement, the quality-department-led study targeted on-time starts rather than turnover, and the administration-led study reported the second-largest turnover reduction without statistical testing. Four observations across four different leading professions, four different outcome sets and four different settings cannot support inference about leadership models.

The asymmetry in Figure 4(b) is the review's central descriptive finding. Surgical technologists and scrub practitioners appear as participants in half the studies, and in the two largest-effect studies their tasks — tray preparation, room readiness, parallel setup — are explicitly among the mechanisms of improvement. Yet they never appear as project leads, and in four studies they are not mentioned at all. The omission is notable given that instrument setup is the largest single source of turnover variability (Smit et al., 2026), that the relevant competencies are formally and exclusively held by this group (von Vogelsang et al., 2019), and that redefinition of roles and responsibilities is an established category of turnover intervention (Cohen et al., 2023).

The professional group most directly engaged in executing OR turnover has not led a single published LSS turnover intervention in this literature.

4.6 Process capability metric reporting (RQ3)

No study reported a process sigma level, DPMO or process capability index. Zero of twelve.

This includes four studies explicitly presenting themselves as LSS or DMAIC interventions. All twelve evaluated success through mean or median time reductions, percentage point changes in rate outcomes, or opportunity-cost projections.

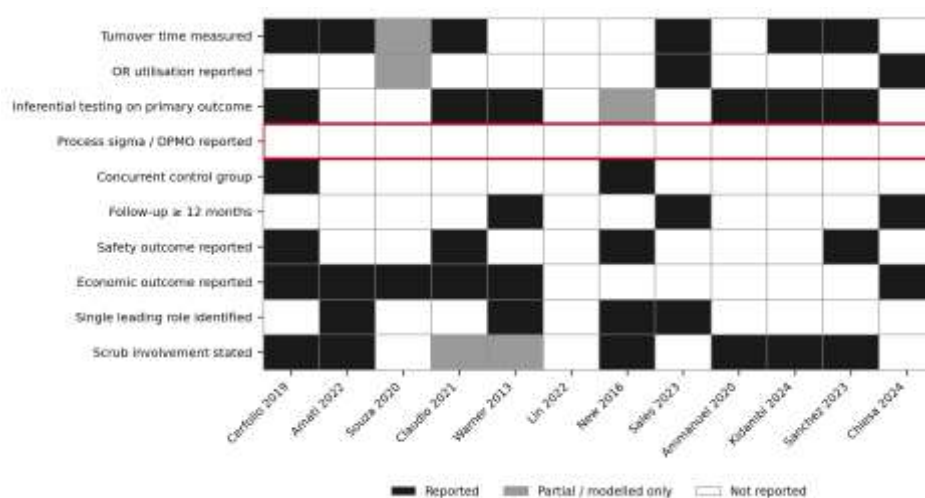


Figure 5. Reporting completeness across the twelve included studies

The implication is not merely incomplete reporting. Six Sigma is constituted by the measurement of variation against specification; a project that adopts the DMAIC sequence while evaluating only central tendency has imported the method's procedural architecture without its measurement logic. Notably, two studies did engage variation directly without using Six Sigma vocabulary — Claudio et al. reported reduced standard deviation (5.22 → 1.93) as a primary result, and Sanchez et al. reported dispersion alongside means.

Variation reduction is thus occasionally measured but never expressed in capability terms, which makes the perioperative LSS literature effectively unbenchmarkable against process capability standards in manufacturing or in other healthcare domains. The finding sits within a documented pattern of incomplete improvement reporting (Howell et al., 2015; Hu et al., 2021; Pereira et al., 2022, 2023), but is more specific: what is missing here is not a generic reporting item but the defining measurement of the method claimed.

4.7 Safety and economic outcomes

Safety reporting was sparse. Eight of twelve studies reported no safety outcome at all. New et al. — the only controlled study to measure safety systematically — assessed WHO checklist compliance, glitch rates, complications, readmissions and length of stay, and found **no significant change on any measure**. Two studies reported that no adverse events occurred. Claudio et al. noted a slight infection-rate decrease while explicitly declining to claim causality.

The literature does not support claims that perioperative LSS interventions improve patient safety. It supports only the weaker claim that reported efficiency gains have not been accompanied by detected safety decrements — in a body of studies that mostly did not look. This is more conservative than the conclusion of a recent synthesis reporting consistent safety improvement across 26 LSS intervention studies (Mousli et al., 2025), and the divergence is attributable to scope: that review selected on safety outcomes, whereas the present review selected on efficiency outcomes and found safety measurement largely absent. Read together, the two reviews suggest that perioperative LSS projects targeting efficiency do not routinely verify that safety is preserved.

Table VI. Economic outcomes reported

Study	Outcome type	Key values	Calculation basis
Cerfolio (2019)	Estimated daily ROI	US\$19,500/day return vs US\$1,298/day cost	~US\$150/min OR time; added cases from 70 min eliminated per day
Souza (2020)	Estimated annual savings	US\$388,000–400,000/year	12% operational efficiency gain
Chiesa (2024)	Patient + system savings	NZ\$156,000 (patient indirect) + NZ\$170,400 (system)	Removed appointments and avoided outsourcing
Claudio (2021)	Monthly savings estimate	~US\$13,200/month	2 min × 50 turnovers/week × 4 weeks × US\$33/min
Warner (2013)	Opportunity cost	US\$12,582 over 9 weeks; US\$72,696 annualised	US\$34.61/min net OR-time cost
Amati (2022)	Opportunity cost estimate	~1,500 CHF/room/day	30 min saved × ~50 CHF/min
Remaining six studies	Not reported	—	—

Six studies quantified economic outcomes, all via opportunity-cost models rather than activity-based costing. The imputed value of OR time ranged from US\$33 to US\$150 per minute, a nearly five-fold spread. This mirrors the dispersion in the primary costing literature, where estimates span US\$7 to US\$113 per minute according to method (Christou et al., 2022) and where costs, charges and revenue are frequently conflated despite being non-interchangeable (Ashrafi et al., 2026). Two of the six studies used values close to the accepted cost benchmark of US\$36–37 per minute (Childers and Maggard-Gibbons, 2018), while one used US\$150, a figure closer to published charges than to costs. Cerfolio et al., reporting the largest daily return, explicitly conditioned realisation on payer mix and on whether released OR time was actually filled with additional cases — the correct caveat, since released minutes only convert to value if the freed capacity is used, and staff who cannot leave the room realise no saving at all (Childers and Maggard-Gibbons, 2018).

5. DISCUSSION

5.1 What the evidence supports

Lean and LSS interventions reduce OR turnover time where meaningful slack exists. The effect is real but conditional, and its magnitude is governed by intervention breadth and baseline headroom rather than by tool selection. Practitioners should expect large reductions only where baselines are high and the redesign spans the full workflow, including policy and staffing changes

rather than technique alone — a conclusion convergent with independent syntheses of turnover determinants (Cohen et al., 2023; Madura et al., 2025).

Adjacent process outcomes — first-case on-time starts in particular — show more consistent and better-sustained improvement than turnover itself, and may be the more tractable target (Pedron et al., 2017).

5.2 What the evidence does not support

Three claims common in practitioner discourse are not supported here: that LSS improves OR utilisation (three studies, conflicting directions, no testing); that it improves patient safety in efficiency-focused perioperative projects (eight studies silent, the one rigorous measurement null); and that any particular professional leadership model produces superior results (no comparative analysis exists). The second of these is consistent with the broader finding that Lean interventions show no significant association with health outcomes (Moraros et al., 2016) and that improvement work in this field concentrates on process rather than clinical endpoints (Mason et al., 2015; Mousli et al., 2025).

5.3 The attribution gap as a field-level problem

The convergence on “multidisciplinary team” attribution is understandable as a reporting convention and problematic as an epistemic outcome. It renders the field unable to answer a question its own practitioners routinely ask: who needs to be in the room, with what authority, for a perioperative improvement project to work? The question is not idle. The sustainment literature identifies devolved decision-making responsibility and local change agency as primary facilitators and exclusion of staff from implementation as a primary barrier (Kunnen et al., 2023); employee involvement outperforms leadership as a predictor of safety quality (Ahmed et al., 2025); and drift away from staff ownership toward managerial short cuts is precisely what eroded a decade-long national improvement programme (Robert et al., 2019). A literature that does not record who led cannot test any of this.

The pattern also has a precedent that should give the field pause. Cranley et al. (2018) found unregulated care aides reporting significantly less involvement and empowerment in improvement work than regulated colleagues in the same facilities, and Mitchell and Flin (2008) found that the entire scrub-nurse non-technical skills literature had never examined leadership or decision-making in that role. Two independent bodies of work, approaching from improvement science and from perioperative nursing respectively, have each left the same professional group's leadership unexamined — even though subsequent work established that independent decision-making and leadership are genuine components of the role (Sirevåg et al., 2021).

This matters most where it is least studied. In resource-constrained systems, adding OR capacity is capital-intensive while redesigning task allocation among existing staff is not. Task shifting is already established as a safe and cost-effective response to surgical workforce shortage for appropriately selected tasks (Hoyler et al., 2015; Bognini et al., 2023; Oko et al., 2025), and its recognised prerequisites — defined scopes of practice with associated competencies, and supervision and quality assurance mechanisms (Ashengo et al., 2017; Modi et al., 2025) — are already satisfied for instrumentation competencies in regulated systems (von Vogelsang et al., 2019). Shifting turnover responsibility toward surgical instrumentation professionals is therefore a well-motivated candidate lever, reinforced by the finding that instrument setup is the dominant source of turnover variability (Smit et al., 2026). This review establishes that the lever is entirely untested — not that it is ineffective. Distinguishing absence of evidence from evidence of absence is the appropriate posture, and the current literature permits nothing stronger.

5.4 Construct validity in self-labelled Six Sigma interventions

The complete absence of capability reporting, alongside occasional unlabelled variation analysis, suggests that “Six Sigma” and “DMAIC” function in this literature partly as legitimating vocabulary rather than as specified measurement commitments. The concern is not new in kind — reviews have repeatedly noted loose and inconsistent use of LSS terminology in healthcare (Antony et al., 2018; Henrique and Godinho Filho, 2020) — but the present finding makes it precise and countable: in perioperative efficiency work, the defining metric of the named method is reported in none of the studies that name it. This is a testable proposition and a direct concern for a field that defines itself methodologically. It also has a practical corollary: without capability metrics, perioperative improvement cannot be compared across sites, specialties or time on any common scale, compounding the definitional barriers to benchmarking already documented (Fixler and Wright, 2013a).

6. IMPLICATIONS

6.1 For research

8. **Harmonise turnover-time definitions.** Report interval boundaries explicitly, ideally against the Procedural Times Glossary, and state how delays unrelated to room preparation are handled (Fixler and Wright, 2013b). Segmented, task-based measurement is what makes turnover analysable and accountable (Goldhaber et al., 2023).
9. **Report role-level accountability.** Identify who led, who held change authority, and which professional groups executed which redesigned tasks. This is a natural extension of the SQUIRE 2.0 requirement to describe the intervention and its context (Ogrinc et al., 2015).
10. **Report capability, not only central tendency.** Sigma level, DPMO or at minimum dispersion with baseline specification limits.
11. **Design for attribution.** Interventions varying the leading professional group across comparable units would answer RQ2 directly; none exists.
12. **Measure safety alongside efficiency.** Efficiency-focused projects should verify that safety is preserved rather than assume it, given that the one controlled safety measurement in this sample was null.
13. **Study resource-constrained systems.** The absence of Spanish-speaking Latin American evidence is a substantive gap, consistent with calls to extend LSS research to low- and middle-income settings (Rathi et al., 2021; Mousli et al., 2025).

6.2 For practice

Expect large turnover gains only from broad redesign at high baselines. Do not use utilisation as a standalone success indicator without controlling the capacity denominator. Verify that segment-level time savings reach system level before projecting financial return, since released time can be reabsorbed upstream and since saved minutes convert to value only if freed capacity is used (Childers and Maggard-Gibbons, 2018). Choose the costing basis deliberately and state it: costs, charges and revenue per OR minute differ by a factor of five and are not interchangeable (Ashrafi et al., 2026). Assign and record role-level accountability at project design, both for management and because it is the only way the field will accumulate knowledge on this question.

6.3 For health systems with regulated surgical instrumentation professions

In systems where surgical instrumentation is a regulated profession with defined competencies, the attribution gap identified here has direct workforce-planning relevance. These professionals hold formal competencies over instrument management and room readiness (von Vogelsang et al., 2019), which constitute the operational core of turnover and its dominant source of variability (Smit et al., 2026). Their complete absence from the leadership of published improvement interventions represents an unexploited and unevaluated capacity lever. The conditions that the task-sharing literature identifies as prerequisites for safe redistribution — defined scope, competency-based evaluation, supervision and quality assurance (Ashengo et al., 2017; Modi et al., 2025) — are institutionally available in such systems, which makes the absence of evaluation an opportunity rather than a caution.

Colombia is one such system, under its mandatory healthcare quality assurance framework and the statutory regulation of surgical instrumentation practice. [cite the specific Colombian statutes and resolutions here, verifying article and current force before submission]

7. LIMITATIONS

Full-text access dominated attrition. Of 251 records meeting abstract-stage eligibility, 205 were excluded solely because full text could not be retrieved. The twelve included studies are therefore better characterised as the accessible subset of the eligible literature than as its totality, and may over-represent open-access publication. This is the review's principal limitation and readers should weight its conclusions accordingly.

Search reproducibility. The semantic search strategy, while broad, is not exactly reproducible, as retrieval indices and models change over time. It was not supplemented by Boolean searches of MEDLINE, Embase, Scopus or Web of Science, nor by

regional databases (LILACS, SciELO) that would have improved coverage of Latin American evidence — a limitation directly relevant to the geographic gap reported in Section 4.1.

Single-reviewer AI-assisted screening. Screening and extraction were conducted by a single AI-assisted pass with author verification of all reported numeric values, rather than by two independent human reviewers throughout, and inter-rater agreement statistics are therefore unavailable.

Design quality of included studies. Ten of twelve lacked concurrent controls. Hawthorne effects were acknowledged as a threat by the authors of five studies. Secular trends, co-interventions and regression to the mean are uncontrolled in most. Only two studies reported follow-up beyond twelve months, and one explicitly warned that gains may extinguish as staff revert to prior habits. Sustainability of turnover-time reduction is essentially undocumented, consistent with the wider pattern in this field (Glasgow et al., 2010; Samanta et al., 2022; Kunnen et al., 2023).

No meta-analysis. Definitional heterogeneity, incomplete dispersion reporting and small study numbers precluded quantitative pooling. Pooling these estimates would have produced a numerically precise but substantively uninterpretable result.

8. CONCLUSION

Lean and Lean Six Sigma interventions reduce operating room turnover time when baselines are high and redesign is broad, with reductions in this review ranging from negligible to 62 per cent. Evidence on operating room utilisation is too sparse and inconsistent to support conclusions, and evidence on patient safety in efficiency-focused perioperative projects is largely absent.

The review's more consequential findings concern what this literature does not report. No study reported process sigma or DPMO, including studies self-identifying as DMAIC interventions. Two-thirds attributed leadership to an unspecified multidisciplinary team, none was led by perioperative nursing or surgical instrumentation professionals, and no study compared outcomes by professional role — despite scrub practitioners executing the turnover tasks that constitute the primary outcome in half the included studies, and despite instrument setup being the largest documented source of turnover variability.

A field organised around measurement discipline has, in this domain, systematically omitted both its defining process metric and the identity of its agents. Until both are reported, perioperative Lean Six Sigma will remain unable to say which of its gains are attributable to whom, or to benchmark its performance on any common capability scale.

REFERENCES

- [1] Ahmed, S., Hasan, M.Z. and Islam, M.A. (2025), “Exploring the role of green LSS and employee involvement on quality improvement of patient safety”, *International Journal of Quality & Reliability Management*. <https://doi.org/10.1108/ijqrm-07-2025-0245>
- [2] Amati, M., Valnegri, A., Bressan, A., et al. (2022), “Reducing changeover time between surgeries through Lean thinking: an action research project”, *Frontiers in Medicine*, Vol. 9. <https://doi.org/10.3389/fmed.2022.822964>
- [3] Ammanuel, S.G., Chan, A., DiGiorgio, A., et al. (2020), “Perioperative anesthesia Lean implementation is associated with increased operative efficiency in posterior cervical surgeries at a high-volume spine center”, *Neurospine*. <https://doi.org/10.14245/ns.1938318.159>
- [4] Antony, J., Palsuk, P., Gupta, S., et al. (2018), “Six Sigma in healthcare: a systematic review of the literature”, *International Journal of Quality & Reliability Management*, Vol. 35 No. 5. <https://doi.org/10.1108/ijqrm-02-2017-0027>
- [5] Ashengo, T., Skeels, A., Hurwitz, E.J.H., et al. (2017), “Bridging the human resource gap in surgical and anesthesia care in low-resource countries: a review of the task sharing literature”, *Human Resources for Health*, Vol. 15 No. 1. <https://doi.org/10.1186/s12960-017-0248-6>
- [6] Ashrafi, A., et al. (2026), “Costs, charges, and revenue of hospital operating rooms in California”, *JAMA Surgery*. <https://doi.org/10.1001/jamasurg.2026.2355>

- [7] Bognini, M., Johnson, W., Oliphant, R., et al. (2023), "Assessing the impact of anaesthetic and surgical task-shifting globally: a systematic literature review", *Health Policy and Planning*, Vol. 38 No. 8. <https://doi.org/10.1093/heapol/czad059>
- [8] Cadeddu, S.B.M., Dare, L.O. and Denis, J.-L. (2023), "Employee-driven innovation in health organizations: insights from a scoping review", *International Journal of Health Policy and Management*. <https://doi.org/10.34172/ijhpm.2023.6734>
- [9] Cerfolio, R., Ferrari-Light, D., Ren-Fielding, C., et al. (2019), "Improving operating room turnover time in a New York City academic hospital via Lean", *Annals of Thoracic Surgery*, Vol. 107 No. 4. <https://doi.org/10.1016/j.athoracsur.2018.11.071>
- [10] Chen, Y., et al. (2026), "Facilitators of and barriers to teamwork between operating room nurses and other practitioners: a meta-synthesis of qualitative studies", *BMJ Open*. <https://doi.org/10.1136/bmjopen-2024-098386>
- [11] Chiesa, M., Reeves, G.M.B., Harper, C., et al. (2024), "Increasing access to cataract surgery in Counties Manukau by optimising the clinical pathway: a quality improvement report", *New Zealand Medical Journal*. <https://doi.org/10.26635/6965.6398>
- [12] Childers, C.P. and Maggard-Gibbons, M. (2018), "Understanding costs of care in the operating room", *JAMA Surgery*, Vol. 153 No. 4, e176233. <https://doi.org/10.1001/jamasurg.2017.6233>
- [13] Christou, C., Oliver, R.A., Rawlinson, J., et al. (2022), "The process of estimating the cost of surgery: providing a practical framework for surgeons", *International Journal of Health Planning and Management*, Vol. 37 No. 4. <https://doi.org/10.1002/hpm.3431>
- [14] Claudio, D., Cosgriff, V., Nino, V. and Valladares, L. (2021), "An agile standardized work procedure for cleaning the operating room", *Journal of Industrial Engineering and Management*, Vol. 14 No. 3. <https://doi.org/10.3926/jiem.3440>
- [15] Coales, K., Hamilton, M., Ryan, G., et al. (2023), "Perspectives of health workers engaging in task shifting to deliver health care in low-and-middle-income countries: a qualitative evidence synthesis", *Global Health Action*, Vol. 16 No. 1. <https://doi.org/10.1080/16549716.2023.2228112>
- [16] Cohen, T.N., Kanji, F.F., Wang, A.S., et al. (2022), "The application of human factors engineering to reduce operating room turnover in robotic surgery", *World Journal of Surgery*, Vol. 46. <https://doi.org/10.1007/s00268-022-06487-z>
- [17] Cohen, T.N., Kanji, F.F. and Zamudio, J. (2023), "Why can't we improve turnover time? A systematic review", *World Journal of Surgery*, Vol. 48 No. 1. <https://doi.org/10.1002/wjs.12015>
- [18] Cranley, L.A., Keefe, J.M., Taylor, D., et al. (2018), "SCOPEOUT: sustainability and spread of quality improvement activities in long-term care — a mixed methods approach", *BMC Health Services Research*, Vol. 18 No. 1. <https://doi.org/10.1186/s12913-018-2978-0>
- [19] Deblois, S. and Lepanto, L. (2016), "Lean and Six Sigma in acute care: a systematic review of reviews", *International Journal of Health Care Quality Assurance*, Vol. 29 No. 2. <https://doi.org/10.1108/ijhcqa-05-2014-0058>
- [20] Fixler, T. and Wright, J.G. (2013a), "Identification and use of operating room efficiency indicators: the problem of definition", *Canadian Journal of Surgery*, Vol. 56 No. 4. <https://doi.org/10.1503/cjs.020712>
- [21] Fixler, T. and Wright, J.G. (2013b), "Comment on 'Identification and use of operating room efficiency indicators: the problem of definition'", *Canadian Journal of Surgery*, Vol. 56 No. 5. <https://doi.org/10.1503/cjs.020813>
- [22] Fulton, B.D., Scheffler, R.M., Sparkes, S.P., et al. (2011), "Health workforce skill mix and task shifting in low income countries: a review of recent evidence", *Human Resources for Health*, Vol. 9 No. 1. <https://doi.org/10.1186/1478-4491-9-1>
- [23] Gagnon, J., et al. (2024), "Decision-maker roles in healthcare quality improvement projects: a scoping review", *BMJ Open Quality*, Vol. 13 No. 1. <https://doi.org/10.1136/bmjopen-2023-002522>

- [24] Glasgow, J.M., Scott-Caziewell, J.R. and Kaboli, P.J. (2010), "Guiding inpatient quality improvement: a systematic review of Lean and Six Sigma", *Joint Commission Journal on Quality and Patient Safety*, Vol. 36 No. 12. [https://doi.org/10.1016/s1553-7250\(10\)36081-8](https://doi.org/10.1016/s1553-7250(10)36081-8)
- [25] Goldhaber, N., et al. (2023), "Surgical pit crew: initiative to optimise measurement and accountability for operating room turnover time", *BMJ Health & Care Informatics*, Vol. 30 No. 1. <https://doi.org/10.1136/bmjhci-2023-100741>
- [26] Goodman, D., Ogrinc, G., Davies, L., et al. (2016), "Explanation and elaboration of the SQUIRE (Standards for Quality Improvement Reporting Excellence) guidelines, V.2.0", *BMJ Quality & Safety*, Vol. 25 No. 12. <https://doi.org/10.1136/bmjqs-2015-004480>
- [27] Healey, T., El Othmani, M.M., Healey, J., et al. (2015), "Improving operating room efficiency, part 1: general managerial and preoperative strategies", *JBJS Reviews*, Vol. 3 No. 10. <https://doi.org/10.2106/jbjs.rvw.n.00109>
- [28] Henrique, D.B. and Godinho Filho, M. (2020), "A systematic literature review of empirical research in Lean and Six Sigma in healthcare", *Total Quality Management & Business Excellence*, Vol. 31 No. 3-4. <https://doi.org/10.1080/14783363.2018.1429259>
- [29] Howell, V., Schwartz, A.E., O'Leary, J.D. and McDonnell, C. (2015), "The effect of the SQUIRE (Standards of Quality Improvement Reporting Excellence) guidelines on reporting standards in the quality improvement literature: a before-and-after study", *BMJ Quality & Safety*, Vol. 24 No. 6. <https://doi.org/10.1136/bmjqs-2014-003737>
- [30] Hoyler, M., Finlayson, S.R.G., McClain, C.D., et al. (2015), "Surgical care by non-surgeons in low-income and middle-income countries: a systematic review", *The Lancet*, Vol. 385. [https://doi.org/10.1016/s0140-6736\(15\)60837-6](https://doi.org/10.1016/s0140-6736(15)60837-6)
- [31] Hu, Z., Wu, Y., Shi, J., et al. (2021), "Completeness of reporting of quality improvement studies in neonatology is inadequate: a systematic literature survey", *BMJ Open Quality*, Vol. 10 No. 2. <https://doi.org/10.1136/bmjoc-2020-001273>
- [32] Kang, E., Massey, D. and Gillespie, B.M. (2015), "Factors that influence the non-technical skills performance of scrub nurses: a prospective study", *Journal of Advanced Nursing*, Vol. 71 No. 12. <https://doi.org/10.1111/jan.12743>
- [33] Kidambi, T., Trieu, H., Lilenstein, B., et al. (2024), "LEAN methodology to improve endoscopy unit efficiency in a multi-subspecialty ambulatory surgery center: a pilot study", *Cureus*. <https://doi.org/10.7759/cureus.69447>
- [34] Kim, H., et al. (2026), "Communication skills and organizational silence as predictors of perioperative competence in operating room nurses: a cross-sectional study", *BMC Nursing*. <https://doi.org/10.1186/s12912-026-04969-2>
- [35] Kirchner, J.E., Parker, L.E., Bonner, L.M., et al. (2012), "Roles of managers, frontline staff and local champions, in implementing quality improvement: stakeholders' perspectives", *Journal of Evaluation in Clinical Practice*, Vol. 18 No. 1. <https://doi.org/10.1111/j.1365-2753.2010.01518.x>
- [36] Kunnen, Y.S., Roemeling, O.P. and Smailhodzic, E. (2023), "What are barriers and facilitators in sustaining lean management in healthcare? A qualitative literature review", *BMC Health Services Research*, Vol. 23 No. 1. <https://doi.org/10.1186/s12913-023-09978-4>
- [37] Lee, P., et al. (2025), "Unpacking the behavioral mechanisms of TQM: evidence from airport ground operations", *The TQM Journal*. <https://doi.org/10.1108/tqm-05-2025-0325>
- [38] Lin, C., Chueh, J., Chen, H.-M., et al. (2022), "Applying the Toyota production system to decrease the time required to transport patients undergoing surgery from the general ward to the operating room", *Frontiers in Medicine*, Vol. 9. <https://doi.org/10.3389/fmed.2022.1054583>
- [39] Madura, G., Elliot, M. and Frendl, D.M. (2025), "What affects operating room turnover time? A systematic review and mapping of the evidence", *Surgery*, Vol. 181, 109263. <https://doi.org/10.1016/j.surg.2025.109263>
- [40] Mason, S.E., Nicolay, C.R. and Darzi, A. (2015), "The use of Lean and Six Sigma methodologies in surgery: a systematic review", *The Surgeon*, Vol. 13 No. 2. <https://doi.org/10.1016/j.surge.2014.08.002>

- [41] McDermott, O., Antony, J., Bhat, S., et al. (2022a), "Lean Six Sigma in healthcare: a systematic literature review on motivations and benefits", *Processes*, Vol. 10 No. 10, 1910. <https://doi.org/10.3390/pr10101910>
- [42] McDermott, O., Antony, J., Sony, M., et al. (2022b), "Lean Six Sigma in healthcare: a systematic literature review on challenges, organisational readiness and critical success factors", *Processes*, Vol. 10 No. 10, 1945. <https://doi.org/10.3390/pr10101945>
- [43] Mitchell, L. and Flin, R. (2008), "Non-technical skills of the operating theatre scrub nurse: literature review", *Journal of Advanced Nursing*, Vol. 63 No. 1. <https://doi.org/10.1111/j.1365-2648.2008.04695.x>
- [44] Modi, P.K., et al. (2025), "Task shifting and task sharing in surgical care", *Annals of Surgery Open*. <https://doi.org/10.1097/as9.0000000000000603>
- [45] Moraros, J., Lemstra, M. and Nwankwo, C. (2016), "Lean interventions in healthcare: do they actually work? A systematic literature review", *International Journal for Quality in Health Care*, Vol. 28 No. 2. <https://doi.org/10.1093/intqhc/mzv123>
- [46] Mousavi Isfahani, H., Tourani, S. and Seyedin, H. (2019), "Lean management approach in hospitals: a systematic review", *International Journal of Lean Six Sigma*, Vol. 10 No. 1. <https://doi.org/10.1108/ijlss-05-2017-0051>
- [47] Mousli, H.M., El-Masry, H.A. and Farag, H. (2025), "Lean Six Sigma interventions for enhancing patient safety-related outcomes: a systematic review", *International Journal of Lean Six Sigma*, Vol. 17 No. 4. <https://doi.org/10.1108/ijlss-07-2025-0194>
- [48] New, S., Hadi, M., Pickering, S.P., et al. (2016), "Lean participative process improvement: outcomes and obstacles in trauma orthopaedics", *PLoS ONE*, Vol. 11 No. 4. <https://doi.org/10.1371/journal.pone.0152360>
- [49] Niñerola, A., Sánchez-Rebull, M.-V. and Hernández-Lara, A.-B. (2020), "Quality improvement in healthcare: Six Sigma systematic review", *Health Policy*, Vol. 124 No. 4. <https://doi.org/10.1016/j.healthpol.2020.01.002>
- [50] Ogrinc, G., Davies, L., Goodman, D., et al. (2015), "SQUIRE 2.0 (Standards for Quality Improvement Reporting Excellence): revised publication guidelines from a detailed consensus process", *BMJ Quality & Safety*, Vol. 25 No. 12. <https://doi.org/10.1136/bmjqs-2015-004411>
- [51] Oko, C., et al. (2025), "Economics of task-shifting in surgery: a systematic review", *Health Science Reports*, Vol. 8 No. 6. <https://doi.org/10.1002/hsr2.71198>
- [52] Parand, A., Burnett, S., Benn, J., et al. (2011), "The disparity of frontline clinical staff and managers' perceptions of a quality and patient safety initiative", *Journal of Evaluation in Clinical Practice*, Vol. 17 No. 6. <https://doi.org/10.1111/j.1365-2753.2010.01506.x>
- [53] Pedron, S., Winter, V., Oppel, E.-M. and Bialas, E. (2017), "Operating room efficiency before and after entrance in a benchmarking program for surgical process data", *Journal of Medical Systems*, Vol. 41 No. 10. <https://doi.org/10.1007/s10916-017-0798-0>
- [54] Pereira, D.D., et al. (2022), "Assessing the quality of reporting on quality improvement initiatives in breast reconstruction: a systematic review", *Plastic and Reconstructive Surgery*. <https://doi.org/10.1097/prs.00000000000009983>
- [55] Pereira, D.D., et al. (2023), "Assessing the quality of reporting on quality improvement initiatives in plastic surgery: a systematic review", *Journal of Plastic, Reconstructive & Aesthetic Surgery*. <https://doi.org/10.1016/j.bjps.2023.01.036>
- [56] Rathi, R., Vakharia, A. and Shadab, M. (2021), "Lean six sigma in the healthcare sector: a systematic literature review", *Materials Today: Proceedings*, Vol. 50. <https://doi.org/10.1016/j.matpr.2021.05.534>
- [57] Robert, G., Sarre, S., Maben, J., et al. (2019), "Exploring the sustainability of quality improvement interventions in healthcare organisations: a multiple methods study of the 10-year impact of the 'Productive Ward: Releasing Time to Care' programme in English acute hospitals", *BMJ Quality & Safety*, Vol. 29 No. 1. <https://doi.org/10.1136/bmjqs-2019-009457>

- [58] Sales, M., Castro, R. de, Aguilar, A.O.D.E. and Ibáñez, V.M. (2023), “Lean healthcare: improving surgical process indicators through prioritization projects”, *Journal of Industrial Engineering and Management*, Vol. 16 No. 3. <https://doi.org/10.3926/jiem.4628>
- [59] Samanta, A.K., Varaprasad, G. and Padhy, R.K. (2022), “Implementing lean six sigma in health care: a review of case studies”, *International Journal of Lean Six Sigma*, Vol. 13 No. 6. <https://doi.org/10.1108/ijlss-08-2021-0133>
- [60] Sanchez, A., Herrera, L., Teixeira, A., et al. (2023), “Improving efficiency and reducing costs in robotic surgery: a Lean Six Sigma approach to optimize turnover time”, *Journal of Robotic Surgery*, Vol. 17. <https://doi.org/10.1007/s11701-023-01606-x>
- [61] Schock, G., et al. (2019), “Operating room turnover time: definitions and future research needs”, *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Vol. 63 No. 1. <https://doi.org/10.1177/1071181319631301>
- [62] Schoeneberg, K., et al. (2023), “The economic impact of standardization and digitalization in the operating room: a systematic literature review”, *Journal of Medical Systems*, Vol. 47 No. 1. <https://doi.org/10.1007/s10916-023-01945-0>
- [63] Sirevåg, I., Tjøflåt, I. and Hansen, B.S. (2021), “A Delphi study identifying operating room nurses' non-technical skills”, *Journal of Advanced Nursing*, Vol. 77 No. 12. <https://doi.org/10.1111/jan.15064>
- [64] Smit, R.D., et al. (2026), “Artificial intelligence-powered analysis of operating room turnover: impact of instrument burden”, *Journal of Neurosurgery*. <https://doi.org/10.3171/2025.9.jns251703>
- [65] Smith, T.S., et al. (2022), “Cost of OR time is \$46.04 per minute”, *Journal of Orthopaedic Business*, Vol. 2 No. 4. <https://doi.org/10.55576/job.v2i4.23>
- [66] Souders, C.P., Catchpole, K.R., Wood, L.N., et al. (2017), “Reducing operating room turnover time for robotic surgery using a motor-racing pit-stop model”, *World Journal of Surgery*, Vol. 41 No. 8. <https://doi.org/10.1007/s00268-017-3936-4>
- [67] Souza, T.A., Vaccaro, G. and Lima, R.M. (2020), “Operating room effectiveness: a lean health-care performance indicator”, *International Journal of Lean Six Sigma*, Vol. 11 No. 5. <https://doi.org/10.1108/ijlss-12-2017-0141>
- [68] von Vogelsang, A.-C., Swenne, C.L., Darling, S. and Åkesdotter Gustafsson, B. (2019), “Operating theatre nurse specialist competence to ensure patient safety in the operating theatre: a discursive paper”, *Nursing Open*, Vol. 7 No. 2. <https://doi.org/10.1002/nop2.424>
- [69] Wang, J., et al. (2025), “A systematic review of Lean implementation in hospitals: impact on efficiency, quality, cost, and satisfaction”, *International Journal of Health Policy and Management*. <https://doi.org/10.34172/ijhpm.8974>
- [70] Warner, C., Walsh, D., Horvath, A.J., et al. (2013), “Lean principles optimize on-time vascular surgery operating room starts and decrease resident work hours”, *Journal of Vascular Surgery*, Vol. 58 No. 5. <https://doi.org/10.1016/j.jvs.2013.05.007>
- [71] Zhang, C., et al. (2026), “Research on the application of refined operating room turnover efficiency in cross-hospital operating room efficiency evaluation”, *BMC Surgery*. <https://doi.org/10.1186/s12893-026-03569-w>