



Improving operating room turnover efficiency with a real-time workflow coordination software in adult degenerative spine surgery

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Background: Operating room (OR) efficiency represents a critical determinant of surgical productivity, cost-effectiveness, workforce wellness, and patient access to care. Among its modifiable components, turnover time (TOT), the interval between patient exit and subsequent patient entry, is a key target for operational improvement. This study describes the impact of the S1 Pit Crew™ platform, a real-time, role-based OR workflow coordination software, on TOT using adult degenerative spine surgery as a representative test environment.

Methods: This study examined prospectively collected perioperative and turnover workflow data from 51 consecutive elective adult degenerative spine surgery cases performed at a single hospital following S1 Pit Crew™ platform implementation. Baseline TOT was derived from institutional records of cases performed over the year preceding implementation and was used for descriptive comparison. The platform delivered real-time, role-specific task prompts and shared situational awareness across all perioperative team members via synchronized multi-device displays, enabling prospective collection of turnover and perioperative workflow data. A total of 24-time parameters were collected and aggregated into four key time interval durations including Stage 1: perioperative time interval #1 (dressing to wheels-out); Stage 2: turnover time (wheels-out to wheels-in); Stage 3: perioperative time interval #2 (wheels-in to incision); and total elapsed skin-to-skin time. Cases were stratified into initial (N=26) and subsequent (N=25) cohorts to assess efficiency with continued utilization and key time interval durations were also compared across procedure types, surgeon, OR, and case order.

Results: Mean TOT was 26.5 minutes following platform implementation, compared with a baseline institutional average of 38.0 minutes, representing a 30.3% descriptive difference. TOT decreased significantly between the initial (28.9±7.7 minutes) and subsequent cohort (23.9±3.7 minutes) (P=0.02). Perioperative time intervals did not differ significantly between initial and subsequent cohorts (P>0.05). All key time interval durations were similar across procedure types, surgeons, ORs, and case order (P>0.05).

Conclusions: After implementation of the S1 Pit Crew™ platform, mean TOT was descriptively 30.3% lower than the prior institutional baseline, with improvement observed with continued utilization and similar time durations across procedure types of varying complexity. Through standardizing workflow with

real-time, shared task visibility, the platform functions as a behavioral coordination tool while also promoting accountability and enabling identification of inefficiencies. Real-time workflow coordination through the S1 Pit Crew™ platform may represent a scalable approach to improving OR efficiency across surgical environments.

Keywords: Turnover time (TOT); operating room efficiency (OR efficiency); perioperative workflow; spine surgery; quality improvement

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Introduction

Operating room (OR) efficiency represents a critical determinant of surgical productivity, cost-effectiveness, and patient access to care (1-3). Among the modifiable components of OR efficiency, OR turnover time (TOT), defined as the interval between patient exit and subsequent

patient entry, has emerged as a key target for operational improvement.

TOT accounts for 39–42% of total non-operative time between cases, which can reach 40–60% of total room utilization (2,4,5). Combined with other non-operative delays, TOT contributes to surgeons spending approximately 25% of their workday in non-operative delays and less than 50% of a 10-hour surgical day operating (6-8). Consequently, prolonged TOT has been identified as a leading source of job-related frustration in national surgeon surveys, with OR inefficiencies and delays being cited as among the greatest well-being threats to surgeons (9,10). The financial implications of TOT are also substantial, with OR time estimated to cost between \$36 and \$150 per minute (1,3). Beyond direct costs, prolonged TOT diminishes patient throughput and surgical capacity, contributing to extended surgical wait times and patient dissatisfaction (2,3,11,12). Collectively, these findings highlight TOT optimization as a high-yield strategy with implications of increasing surgical capacity, reducing staff burden, and lowering institutional costs across surgical specialties (3,4,13).

Despite its importance, turnover remains highly variable, arising from the fact that it requires coordination of multiple sequential and parallel tasks across environmental services, nursing, anesthesia, and surgical teams, each with distinct roles and timing constraints. Prior studies have highlighted team motivation, familiarity, and role clarity as key drivers of efficiency (4,14). Breakdowns in coordination, such as delayed environmental services entry or conflicts between floor-cleaning processes and sterile instrument setup, lead to cascading delays (14). A recent systematic review by Cohen *et al.* (15) demonstrated that interventions focused on process redesign, parallel task execution, clear role delineation, and improved team communication achieved the largest reductions in TOT (up to 62%), whereas education or financial incentives alone showed inconsistent benefit.

Highlight box

Key findings

- S1 Pit Crew™ platform implementation resulted in a mean turnover time of 26.5 minutes, a 30.3% descriptive difference compared to the baseline institutional average of 38.0 minutes, with statistically significant improvement observed in turnover time with continued platform use and consistent key time intervals across varying procedural complexities.

What is known and what is new?

- Turnover time is a major source of operating room inefficiency, requiring coordination of multiple sequential and parallel tasks across environmental services, nursing, anesthesia, and surgical teams, each with distinct roles and timing constraints.
- The S1 Pit Crew™ platform is a real-time, role-based operational coordination software that provides live task visibility and shared situational awareness within a universal, reproducible protocol during turnover time and perioperative stages. Granular time-stamped data also enables real-time identification of inefficiencies for targeted education and process improvement, while shared task visibility fosters transparency and accountability.

What is the implication, and what should change now?

- This study suggests that embedding real-time, role-based coordination and establishing a universal, reproducible workflow protocol with real-time visibility across all team members may enable durable efficiency improvements in turnover time without altering staffing models or procedural complexity. Therefore, real-time workflow coordination through the S1 Pit Crew™ platform may represent a scalable approach to improving operating room efficiency across surgical environments.

Together, these findings suggest that turnover inefficiency is likely driven by coordination failures.

Prior OR turnover interventions have included pit crew models (3), retrospective data reporting (13), systems-based redesign (16), and surgeon-led approaches (17). Many of these strategies involve procedural modifications, staffing changes, or sustained reliance on local leadership and manual adherence by OR personnel to maintain effectiveness. Moreover, institutional inertia and ingrained organizational norms frequently impede implementation. For example, the “Performance Improvement Team” intervention, which deployed lean and value stream mapping methodologies, required the elimination of seven institutional dogmas and the modification of three hospital policies, relied on dedicated personnel, and faced labor-related constraints that limited scalability and sustainability (3).

To overcome these barriers, an intervention targeting real-time coordination of existing tasks without altering surgical technique, staffing models, instrumentation, or care pathways was developed with the aim to directly improve the efficiency of existing workflows. The S1 Pit Crew™ platform is a real-time, role-based operational coordination software that provides live task visibility and shared situational awareness within a universal, reproducible workflow protocol during case turnover and perioperative stages. Additionally, granular time-stamped data tracked across all perioperative and turnover stages enables systematic identification of potential inefficiencies for targeted educational and quality improvement initiatives. The primary objective of this study was to describe the effect of S1 Pit Crew™ platform implementation on OR TOT in adult degenerative spine surgery as a representative test environment, with secondary analyses examining additional perioperative stages to assess broader workflow effects. We hypothesized that platform implementation would result in descriptively lower OR TOT, with progressive improvement in TOT observed over continued use. We present this article in accordance with the STROBE reporting checklist (available at <https://jss.amegroups.com/article/view/10.21037/jss-2026-0099/rc>).

Methods

Study design and setting

This study was a retrospective analysis of prospectively collected perioperative workflow data from consecutive elective spine surgical cases performed at Sharp Grossmont

Hospital, a single regional major hospital center from September 30, 2025 to December 17, 2025 following implementation of the S1 Pit Crew™ platform, and was conducted in accordance with the Declaration of Helsinki and its subsequent amendments. A total of 51 consecutive surgical cases performed by three fellowship-trained spine surgeons (P.D.K., E.N., R.R.) over the 3-month period were included. Eligible cases were limited to adult degenerative, non-deformity spine procedures and ORs with more than one scheduled case per day to necessitate a turnover interval. Cases involving spinal deformity (more than four levels), trauma, tumor, infection, emergent procedures, or ORs with a single scheduled case per day were excluded. Baseline TOT was defined as the average institutional TOT the year prior to platform implementation and served strictly as a descriptive comparator without inclusion in inferential statistical testing. This value was derived from cases following identical inclusion and exclusion criteria performed by the same three fellowship-trained spine surgeons over the preceding year, with no institutional changes to the operative environment between periods. This project constituted a quality improvement protocol, therefore exempt from informed consent and Institutional Review Board approval (Sharp HealthCare Institutional Review Board).

Operational workflow platform and time interval definitions

The S1 Pit Crew™ platform coordination software provides live task visibility, role-specific prompts, and shared situational awareness across surgical, anesthesia, and nursing teams. Real-time displays of stage status, role assignments, and elapsed time were continuously visible across all connected devices, with task completion notifications to all devices prompting initiation of subsequent role-specific tasks. The platform tracked a standardized sequence of role-specific tasks throughout each key time interval resulting in a total of 24-time parameters collected from skin to skin, including 10 discrete events within the turnover interval alone. These 24 time stages were aggregated and categorized into four standardized key time intervals of interest: Stage 1: perioperative interval #1, the time from placement of the initial sterile dressing to wheels-out of the patient; Stage 2: turnover time, the time from wheels-out of the preceding patient to wheels-in of the subsequent patient; Stage 3: perioperative interval #2, the time from wheels-in to skin

incision of the subsequent case; Total Elapsed time from skin to skin, the cumulative time from sterile dressing placement of the prior case to incision of the subsequent case. These intervals were utilized to isolate discrete operational phases common to all surgical cases.

Platform training and data collection

Initial training was provided by the surgeon who developed the S1 Pit Crew™ platform (R.R.). This consisted of formal onboarding requiring approximately 15 minutes per nurse using a mobile device. Based on anecdotal feedback, nurses typically require 2–3 operative turnovers to become fully comfortable and synchronized with app usage in real-world workflow. Subsequent dissemination of training across OR staff occurred through peer-to-peer, nurse-led instruction.

Perioperative workflow data were prospectively recorded using two devices: one hospital-issued mobile iPad on a rolling stand in the OR and one hospital-issued iPhone used by the circulating nurse. The surgeons had the software downloaded on their individual devices. Typically, the OR included one surgical tech, one surgical tech float, one circulating nurse, one circulating nurse float, one surgical representative, one radiology tech, one neurophysiologist, one anesthesiologist, one surgeon, one physician's assistant, and two environmental service employees. The tasks were input as complete by the person responsible for that task or by proxy via the mobile iPad when direct self-entry was not feasible. To minimize documentation latency and preserve temporal accuracy, the responsible role player verbally confirmed task completion immediately upon finishing, at which point the nearest available staff member registered the task on the mobile iPad. When present, the circulating nurse served as the designated proxy entry individual, given their non-sterile role and proximity to the device. Scrubbed surgical techs, who are unable to directly access the device during sterile portions of the case, routinely utilized this proxy entry process. TOT, defined by the directly observed events of wheels-out and wheels-in, was consistently recorded in real time without proxy.

Procedure type and delay classification

Surgical cases were categorized by subsequent-case procedure type based on the primary operative intervention performed, as the subsequent case primarily determines setup requirements and preparation demands during the turnover interval. Procedure categories included anterior

cervical discectomy and fusion or artificial disc replacement (ACDF/ADR), decompression (including microdiscectomy or laminectomy), anterior lumbar interbody fusion with posterior spinal fusion (ALIF/PSF), anterior lumbar interbody fusion or artificial disc replacement (ALIF/ADR), hardware removal, posterior cervical decompression and fusion (PCDF), sacroiliac joint fusion, and robotic lumbar fusion. This classification was used to describe the distribution of procedures within the cohort and to assess key time intervals across procedure types.

Delays across each respective key time interval were prospectively recorded and categorized by stage and delay type. Stage 1: perioperative time interval #1 delays were classified as post-anesthesia care unit (PACU) holds or non-PACU delays. PACU holds were recorded as discrete events with associated duration, whereas non-PACU delays were documented categorically by primary cause without time duration. Delays occurring during Stage 2: turnover time and Stage 3: perioperative time interval #2 were similarly documented categorically by primary cause without time duration.

Statistical analysis

All continuous variables are reported as mean $\pm$ standard deviation (min–max) or mean $\pm$ standard deviation (min–max); median (interquartile range) when relevant. To evaluate changes in workflow efficiency over time after utilization of the platform, cases were stratified into initial (first 26 case cohort) and subsequent cohorts (second 25 case cohort). To evaluate workflow maturation and learning curve effects following platform utilization, the consecutive case series was prespecified to be divided at its approximate midpoint into two sequential cohorts: an initial cohort (first 26 cases) and a subsequent cohort (last 25 cases). Normality of continuous data was assessed using the Shapiro–Wilk test, with all key time interval variables demonstrating non-normal distributions. Therefore, nonparametric tests were used for all inferential analyses with between-cohort comparisons performed using the Mann–Whitney U test. Baseline TOT (institutional aggregate average over the preceding year) was used for descriptive comparison only and was not included in inferential testing. Accordingly, statistical significance between baseline and post-implementation TOT was not established. To assess whether key workflow intervals differed by procedural and operational characteristics including procedure type, OR assignment, surgeon, and case order, nonparametric

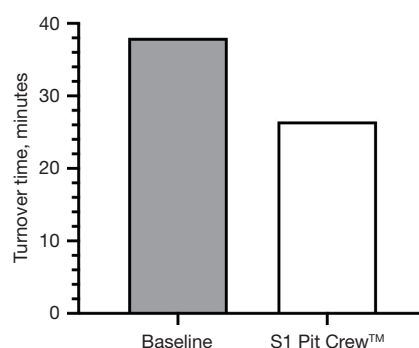


Figure 1 Descriptive comparison of mean turnover time (minutes) at baseline and following S1 Pit Crew™ platform implementation.

Table 1 Durations of key time intervals utilizing the S1 Pit Crew™ platform across all spine cases (N=51)

Time interval (minutes)	Duration
Stage 1: perioperative time interval #1 [†]	12.2±5.1 (4.0–30.7); 11.2 (9.3–14.6)
Stage 2: turnover time [‡]	26.5±6.6 (17.1–50.0); 24.7 (22.9–29)
Stage 3: perioperative time interval #2 [§]	55.6±17.9 (19.6–138.1); 54.6 (47.7–61.2)
Total elapsed time from skin to skin [¶]	82.1±17.7 (55.9–172.8); 80.2 (70.7–88.8)

Values are presented as mean ± standard deviation (min–max); median (interquartile range). [†], time interval from initial sterile dressing placed to wheels-out; [‡], time interval from wheels-out to wheels-in; [§], time interval from wheels-in to next incision; [¶], total time interval from initial sterile dressing placed to next incision for subsequent case.

Kruskal-Wallis tests were used to compare durations of Stage 1: perioperative time interval #1, Stage 2: turnover time, Stage 3: perioperative time interval #2, and total elapsed time from skin-to-skin across each variable. Variables represented by fewer than five cases were excluded from inferential testing. The four procedure types meeting this threshold, ACDF/ADR (n=20), decompression (n=13), ALIF/PSF (n=8), and ALIF/ADR (n=5), were retained for analysis which collectively represents 90.2% of the study cohort. Statistical significance was defined as $P < 0.05$, and all analyses were conducted using SPSS Version 30.0.0.0 (IBM Corp., Armonk, NY).

Results

Study cohort

A total of 51 consecutive degenerative adult spinal surgery cases utilizing the S1 Pit Crew™ platform were included in the study, performed across three ORs by three fellowship trained spine surgeons. The cohort comprised subsequent case procedures of ACDF/ADR (N=20), decompression (N=13), ALIF/PSF (N=8), ALIF/ADR (N=5), hardware

removal (N=2), PCDF (N=1), sacroiliac joint fusion (N=1), and robotic lumbar fusion (N=1).

S1 Pit Crew, Inc™ TOT descriptive comparison with baseline TOT

For descriptive comparison, mean TOT was 26.5±6.6 (17.1–50.0); 24.7 (22.9–29) minutes following implementation of the platform, representing a 30.3% difference compared to the baseline institutional average of 38.0 minutes, as demonstrated in *Figure 1*.

Key time interval durations across all cases

Across all cases, the duration of Stage 1: perioperative time interval #1 was 12.2±5.1 (4.0–30.7); 11.2 (9.3–14.6) minutes. The duration of Stage 2: turnover time was 26.5±6.6 (17.1–50.0); 24.7 (22.9–29) minutes. The duration of Stage 3: perioperative time interval #2 was 55.6±17.9 (19.6–138.1); 54.6 (47.7–61.2) minutes. The total elapsed time from skin-to-skin was 82.1±17.7 (55.9–172.8); 80.2 (70.7–88.8) minutes. Full key time interval durations are demonstrated in *Table 1*.

Table 2 Durations of key time intervals comparing initial and subsequent case cohorts utilizing the S1 Pit Crew™ platform^a

Time interval (minutes)	Initial cohort (N=26)	Subsequent cohort (N=25)	P value ^b
Stage 1: perioperative time interval #1 ^c	12.0±4.9 (4.1–25.8); 11.6 (9.0–14.6)	12.4±5.4 (5.8–30.7); 10.8 (9.3–13.3)	0.93
Stage 2: turnover time ^d	28.9±7.7 (18.9–50.0); 26.3 (23.8–31.9)	23.9±3.7 (17.1–30.1); 24.4 (21.4–26.1)	0.02
Stage 3: perioperative time interval #2 ^e	53.1±22.4 (19.6–138.1); 53.7 (42.2–59.6)	58.3±11.3 (41.5–85.9); 56.3 (50.4–64.1)	0.30
Total elapsed time from skin to skin ^f	82.0±21.5 (55.9–172.8); 80.2 (70.5–88.1)	82.3±13.2 (64.7–114.9); 78.8 (71.8–90.2)	0.73

Values are presented as mean ± standard deviation (min–max); median (interquartile range). ^a, to evaluate changes in workflow efficiency over time utilizing S1 Pit Crew™ platform; cases were stratified into first 26 cases (initial cohort) and subsequent 25 cases (subsequent cohort); ^b, between-group comparisons were performed using the Mann-Whitney U test; bolded values indicate statistical significance (P<0.05); ^c, time interval from initial sterile dressing placed to wheels-out; ^d, time interval from wheels-out to wheels-in; ^e, time interval from wheels-in to next incision; ^f, total time interval from initial sterile dressing placed to next incision for subsequent case.

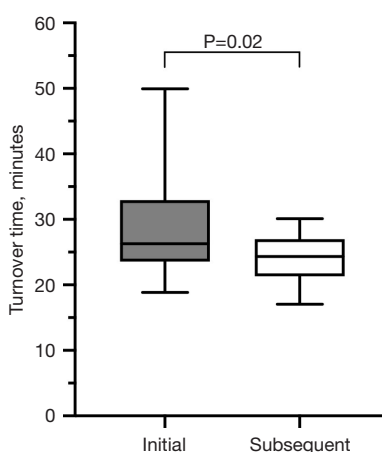


Figure 2 Comparison of turnover time (minutes) between the initial (n=26) and subsequent (n=25) implementation cohorts. The central line represents the median, box borders represent the interquartile range, and the whiskers extend to the minimum and maximum observed values. Between-cohort comparison was performed using the Mann-Whitney U test; P<0.05 was considered statistically significant.

Delays during key time intervals

During Stage 1: perioperative time interval #1, 17.6% (N=9) of cases had PACU holds, with a mean duration of 5.5±5.5 minutes (0.6–16.4). In addition to PACU holds, 11.8% (N=6) of cases had non-PACU delays occur during this stage, attributed to local anesthetic application 3.9% (N=2), block performed after surgery 3.9% (N=2), anatomical constraints 2.0% (N=1), and extubation delay 2.0% (N=1).

During Stage 2: turnover time, 27.5% (N=14) of cases had a delay occur, including patient restroom use 5.9% (N=3), translator use 5.9% (N=3), procedural delay of surgeon 3.9% (N=2), limited staff 2.0% (N=1), sterile processing issue 2.0% (N=1), procedural delay of anesthesia 2.0% (N=1), procedural delay of surgeon and anesthesia 2.0% (N=1), and

other causes 3.9% (N=2). During Stage 3: perioperative time interval #2, none of cases had a delay occur.

Key time intervals by implementation cohorts

Durations of key time intervals comparing initial and subsequent case cohorts are presented in Table 2. Stage 1: perioperative time interval #1 was similar between the initial, 12.0±4.9 (4.1–25.8); 11.6 (9.0–14.6) minutes, and the subsequent implementation cohorts, 12.4±5.4 (5.8–30.7); 10.8 (9.3–13.3) minutes (P=0.93). Stage 2: turnover time was significantly lower in the subsequent implementation cohort, 23.9±3.7 (17.1–30.1); 24.4 (21.4–26.1) minutes, compared to the initial implementation cohort, 28.9±7.7 (18.9–50.0); 26.3 (23.8–31.9) minutes (P=0.02), as demonstrated in Figure 2. Stage 3: perioperative time

Table 3 Duration of key time intervals by subsequent case procedure type utilizing the S1 pit Crew™ platform (N=51)

Procedure type	Stage 1: perioperative time interval #1 [†] (minutes)	Stage 2: turnover time [‡] (minutes)	Stage 3: perioperative time interval #2 [§] (minutes)	Total elapsed time from skin to skin [¶] (minutes)
ALIF/ADR (N=5)	13.3±5.7 (8.9–22.4); 10.5 (9.4–15.5)	26.8±2.5 (24.5–30.4); 26.1 (24.8–28.4)	65.4±12.1 (48.2–82.0); 64.3 (64.1–68.4)	92.2±13.3 (73.0–110.4); 92.9 (90.2–94.7)
ALIF/PSF (N=8)	9.9±3.1 (4.1–14.6); 9.8 (9.0–11.9)	28.3±5.4 (24.1–39.3); 26.5 (24.1–30.7)	53.8±15.1 (19.6–72.0); 56.0 (53.8–60.1)	82.2±11.6 (58.9–99.9); 84.3 (78.3–86.9)
Decompression (N=13)	11.9±2.8 (8.3–18.5); 11.8 (9.9–12.8)	25.1±3.6 (19.9–30.6); 24.4 (22.5–28.1)	52.7±9.9 (32.9–74.3); 54.0 (47.3–56.3)	77.9±10.2 (55.9–94.3); 80.2 (69.8–81.3)
ACDF/ADR (N=20)	13.0±5.0 (5.8–25.8); 11.6 (9.3–16.2)	24.6±6.8 (17.1–44.1); 23.0 (20.5–26.5)	53.7±13.8 (21.0–85.9); 52.3 (49.3–59.8)	78.3±12.4 (64.7–114.9); 77.8 (69.9–80.3)
Hardware removal (N=2)	17.6±18.5 (4.6–30.7); 17.6 (11.1–24.2)	37.6±17.4 (25.3–50.0); 37.6 (31.5–43.8)	52.9±28.6 (32.7–73.1); 52.9 (42.8–63.0)	90.5±11.2 (82.6–98.5); 90.5 (86.6–94.5)
PCDF (N=1)	5.1	34.7	138.1	172.8
Sacro-iliac joint fusion (N=1)	9.7	23.4	47	70.4
Robotic lumbar fusion (N=1)	13.4	36.9	30.5	67.3

Values are presented as mean ± standard deviation (min–max); median (interquartile range). Procedures with N=1 are reported as single observed values. [†], time interval from initial sterile dressing placed to wheels-out; [‡], time interval from wheels-out to wheels-in; [§], time interval from wheels-in to next incision; [¶], total time interval from initial sterile dressing placed to next incision for subsequent case. ACDF, anterior cervical discectomy and fusion; ADR, artificial disc replacement; ALIF, anterior lumbar interbody fusion; PCDF, posterior cervical decompression and fusion; PSF, posterior spinal fusion.

interval #2 was similar between the initial, 53.1±22.4 (19.6–138.1); 53.7 (42.2–59.6) minutes, and the subsequent implementation cohorts, 58.3±11.3 (41.5–85.9); 56.3 (50.4–64.1) minutes (P=0.30). Total elapsed time from skin to skin was similar between the initial 82.0±21.5 (55.9–172.8); 80.2 (70.5–88.1) minutes, and the subsequent implementation cohorts, 82.3±13.2 (64.7–114.9); 78.8 (71.8–90.2) minutes (P=0.73).

Key time interval durations by procedural and operational characteristics

Key time interval durations stratified by subsequent case procedure type are summarized in *Table 3*. For Stage 1: perioperative time interval #1, mean durations (in minutes) were 5.1 for PCDF, 9.7 for sacroiliac joint fusion, 9.9±3.1 (4.1–14.6); 9.8 (9.0–11.9) for ALIF/PSF, 11.9±2.8 (8.3–18.5); 11.8 (9.9–12.8) for decompression, 13.0±5.0 (5.8–25.8); 11.6 (9.3–16.2) for ACDF/ADR, 13.3±5.7 (8.9–22.4); 10.5 (9.4–15.5) for ALIF/ADR, 13.4 minutes for robotic lumbar fusion, and 17.6±18.5 (4.6–30.7); 17.6 (11.1–24.2) for hardware removal. There were no significant differences in Stage 1: perioperative time interval #1 across included procedure types (H(4) =1.8, P=0.61).

For Stage 2: turnover time, mean durations (in minutes), were 23.4 for sacroiliac joint fusion, 24.6±6.8 (17.1–44.1); 23.0 (20.5–26.5) for ACDF/ADR, 25.1±3.6 (19.9–30.6); 24.4 (22.5–28.1) for decompression, 26.8±2.5 (24.5–30.4); 26.1 (24.8–28.4) for ALIF/ADR, 28.3±5.4 (24.1–39.3); 26.5 (24.1–30.7) for ALIF/PSF, 34.7 for PCDF, 36.9 for robotic lumbar fusion, and 37.6±17.4 (25.3–50.0); 37.6 (31.5–43.8) for hardware removal. There were no significant differences in Stage 2: turnover time across included procedure types (H(4) =6.1, P=0.10).

For Stage 3: perioperative time interval #2, mean durations (in minutes) were 30.5 for robotic lumbar fusion, 47.0 for sacroiliac joint fusion, 52.7±9.9 (32.9–74.3); 54.0 (47.3–56.3) for decompression, 52.9±28.6 (32.7–73.1); 52.9 (42.8–63.0) for hardware removal, 53.7±13.8 (21.0–85.9); 52.3 (49.3–59.8) for ACDF/ADR, 53.8±15.1 (19.6–72.0); 56.0 (53.8–60.1) for ALIF/PSF, 65.4±12.1 (48.2–82.0); 64.3 (64.1–68.4) for ALIF/ADR, and 138.1 for PCDF. There were no significant differences in Stage 3: perioperative time interval #2 across included procedure types (H(4) =4.6, P=0.20).

For total elapsed time from skin to skin, mean durations (in minutes) were 67.3 for robotic lumbar fusion, 70.4 for sacroiliac joint fusion, 77.9±10.2 (55.9–94.3); 80.2 (69.8–81.3) for decompression, 78.3±12.4 (64.7–114.9); 77.8 (69.9–80.3)

for ACDF/ADR, 82.2 ± 11.6 (58.9–99.9); 84.3 (78.3–86.9) for ALIF/PSF, 90.5 ± 11.2 (82.6–98.5); 90.5 (86.6–94.5) for hardware removal, 92.2 ± 13.3 (73.0–110.4); 92.9 (90.2–94.7) for ALIF/ADR, and 172.8 for PCDF. There were no significant differences in total elapsed time from skin to skin across procedure types ($H(4) = 6.0$, $P = 0.11$).

No significant differences were identified in Stage 1: perioperative time interval #1 ($H(2) = 1.4$, $P = 0.49$), Stage 2: turnover time ($H(2) = 0.3$, $P = 0.86$), Stage 3: perioperative time interval #2 ($H(2) = 0.4$, $P = 0.83$), and total elapsed time from skin-to-skin ($H(2) = 0.1$, $P = 0.94$) across surgeons. No significant differences were identified in Stage 1: perioperative time interval #1 ($H(3) = 1.9$, $P = 0.59$), Stage 2: turnover time ($H(3) = 1.9$, $P = 0.60$), Stage 3: perioperative time interval #2 ($H(3) = 4.6$, $P = 0.21$), and total elapsed time from skin-to-skin ($H(3) = 5.6$, $P = 0.13$) across ORs. No significant differences were identified in Stage 1: perioperative time interval #1 ($H(2) = 2.3$, $P = 0.32$), Stage 2: turnover time ($H(2) = 2.3$, $P = 0.32$), Stage 3: perioperative time interval #2 ($H(2) = 1.8$, $P = 0.42$), and total elapsed time from skin-to-skin ($H(2) = 2.2$, $P = 0.34$) across case order position.

Discussion

This study found that following S1 Pit Crew™ platform implementation, mean TOT was 26.5 minutes compared with a baseline institutional average of 38.0 minutes, a 30.3% descriptive difference, with statistically significant improvement observed in TOT with continued platform use and consistent key time intervals across varying procedural complexities. These findings suggest that turnover inefficiency is driven by coordination failures and that embedding real-time, role-based coordination into perioperative workflows may enable durable efficiency improvements without altering staffing models or procedural complexity.

OR turnover represents a uniquely coordination-dependent phase of surgical care. Unlike intraoperative efficiency, which is largely determined by surgeon technique and expertise, case complexity, and anatomical factors, turnover requires the synchronized execution of parallel tasks across nursing, anesthesia, environmental services, and surgical teams (16). Delays during this phase are rarely attributable to the duration of individual tasks themselves, but instead often arise from latency between task initiation, unclear role ownership, and fragmented situational awareness (14,18). Previous research has demonstrated that real-time communication interventions, including hands-

free mobile platforms, daily safety huddles, and preoperative briefings, can enhance team situational awareness, restore perioperative staff control, and reduce workflow disruptions (19–22). By enabling real-time task visibility, transparency, and aligning role-specific actions within a shared operational framework, the S1 Pit Crew™ platform may help address these underlying sources of inefficiency by enabling teams to reduce idle time between interdependent tasks rather than accelerating task execution. Reductions in OR inefficiency, a well-being threat and source of surgeon frustration, have the potential for downstream improvements in overall workforce wellness, patient satisfaction, and financial viability, as previously described in the literature (1,3,4,9,10,13,16).

The observed improvement in TOT between the initial and subsequent cohorts with continued platform utilization suggests a behavioral adaptation rather than a transient intervention effect. As teams became familiar with the workflow structure and role expectations embedded within the platform, coordination likely shifted from reactive to anticipatory, potentially leading to the observed improvement of TOTs between cohorts. Interestingly, these efficiency gains were isolated to the turnover interval, which is characterized by highly interdependent, multi-role tasks that are sensitive to improvements in shared situational awareness and coordination. In contrast, perioperative intervals before and after turnover remained similar between cohorts, likely due to these intervals involving more sequential, role-specific tasks, such as anesthesia-led processes including extubation and induction, which are appropriately constrained by patient safety and provider expertise. The absence of change in these intervals may support the interpretation that observed efficiency gains were driven by reductions in coordination-related idle time rather than by task compression or redistribution, reinforcing turnover as the key time interval with the greatest potential to respond to improved real-time coordination. Additionally, although total elapsed time from skin-to-skin did not differ significantly between cohorts, this likely reflects attenuation of the relative improvement in TOT when analyzed as a proportion of the substantially larger total elapsed time, which incorporates preceding and subsequent perioperative stages that are likely less sensitive to coordination-based improvement, as previously described.

In our study, TOTs were similar across case types despite substantial differences in procedural complexity, surgical approach, and equipment requirements. This contrasts with prior literature demonstrating longer TOTs for more complex procedures with greater equipment demands

(13,23). The lack of procedure-related differences observed in this cohort suggests that the S1 Pit Crew™ platform may mitigate complexity-driven variability through improved coordination of tasks universal to all procedure types. As turnover is a universal phase of surgical care, independent of specialty or technique, coordination-based interventions improving this period such as the S1 Pit Crew™ platform may have the potential to be applicable across surgical environments without requiring procedure or specialty specific re-design. However, validation in larger, multi-center, and multi-specialty cohorts will be necessary to establish generalizability.

The identification of residual delays such as translator needs, extubation delays, and sterile processing issues highlights that certain additional sources of operative delay require complementary process-level interventions to further improve OR efficiency. The platform's time-stamped recording of delays across each perioperative stage enables systematic identification of such sources, creating documented opportunities for quality improvement beyond coordination alone.

Qualitative observations suggested rapid behavioral adoption, with teams transitioning from fragmented communication to shared real-time workflow awareness within weeks. Initial concerns regarding task burden diminished as staff recognized the collaborative nature of task entry and shared accountability. From a scalability standpoint, the mobile-based platform facilitated remote training, with successful adoption requiring two nursing champions to train remaining staff and full behavioral adoption achieved within four to six weeks. Administrative support is essential, as consistency across all team members is necessary for optimal coordination.

This study has several limitations. Although TOT was descriptively compared following platform implementation with baseline institutional averages, inferential statistical comparisons was not performed, therefore precluding determination of whether the observed difference represented a statistically significant change following implementation. Future studies should incorporate case-level baseline data across all perioperative stages to enable formal inferential statistical comparisons of pre- and post-implementation time intervals. Additionally, device availability resulted in task completion being recorded by proxy rather than by the individual performing the task at times. This may have introduced latency in documentation and coordination, potentially attenuating full efficiency gains. Future studies will investigate whether optimization

improves with full implementation across individual devices for all OR staff. Moreover, the absence of a contemporaneous control group precludes definitive causal attribution of the observed differences to the platform specifically. Although no significant univariate associations were identified between key time intervals and procedural or operative characteristics, multivariable adjustment was not performed, and sample sizes were limited. Team awareness of the platform may have also independently influenced results; however, such awareness is inherent to the platform's design, as shared transparency, accountability, and real-time task visibility are the specific mechanisms through which the platform targets efficiency gains. Studies incorporating larger sample sizes with concurrent control cohorts are necessary to more definitively understand platform-specific efficacy and represents an area of potential future investigation. This study also was conducted at a single center over a three-month period in a degenerative spine cohort, limiting generalizability to other surgical specialties, institutional environments, and patient populations. In turn, multi-center, multi-specialty prospective studies will be necessary to establish the broader generalizability of these findings.

Conclusions

Following S1 Pit Crew™ platform implementation, mean TOT demonstrated a 30.3% descriptive reduction compared with the prior institutional baseline average, with progressive improvement in TOT observed with continued use and similar key time interval durations across spine procedure types of varying complexity. By establishing a universal, reproducible workflow protocol with real-time visibility across all team members, the platform functions as a behavioral coordination tool, ensuring every team member operates within a standardized framework regardless of OR assignment. Granular time-stamped data enables real-time identification of inefficiencies for targeted education and process improvement, while shared task visibility fosters transparency and accountability—mechanisms that may inherently drive efficiency gains. Real-time workflow coordination through the S1 Pit Crew™ platform may represent a scalable approach to improving OR efficiency across surgical environments.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at <https://jss.amegroups.com/article/view/10.21037/jss-2026-0099/rc>

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. This study was conducted in accordance with the Declaration of Helsinki and its subsequent amendments. This project constituted a quality improvement protocol, therefore exempt from informed consent and Institutional Review Board approval (Sharp HealthCare Institutional Review Board).

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