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Time-driven activity-based costing to model the utility of parallel induction redesign in high-turnover operating lists

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ABSTRACT

Background: Value-based healthcare is strongly advocated to reduce the spiralling rise in healthcare expenditure. Operating room efficiency is an important focus of value-based healthcare delivery due to high costs and associated hospital revenue derived from procedural streams of care. A parallel induction design, utilising induction rooms for anaesthetising patients, may improve operating room efficiency and optimise revenue. We used time-driven activity-based costing (TDABC) to model personnel costs for a high-turnover operating list to assess value of parallel induction redesign.

Methods: We prospectively captured activity data from high-turnover surgery allocated to induction of anesthesia within the operating room (serial design) or within induction rooms prior to completion of preceding surgery (parallel design). Personnel costs were constructed using TDABC following assignment of a case-mix that integrated our activity data. This was contrasted against procedural revenue to assess value of projected case throughput.

Results: Under a parallel induction design, projected operating list duration was reduced by 55 min at marginal increase (1.6%) in personnel costs as assessed by TDABC. This could facilitate an additional short duration surgical case (e.g. Wide Local Excision, with potential additional revenue of \$2818 per day and \$0.73 M per annum per operating room).

Conclusions: Parallel induction design reduces non-operative time at minimal increase in personnel costs for all-day, high turnover surgery. An additional short duration surgical case is likely feasible under this model and represents a value investment with minimal requirement for additional personnel resources.

Implications: A parallel induction design, within the constraints of finite healthcare funding, may help alleviate some of the global increase in demand for surgical capacity that accompanies an expanding and aging population.

1. Background

Optimising costs in operating rooms is of increasing importance amidst rising demand for increased surgical capacity that accompanies globally expanding and aging populations.^{1,2} Although operating room running costs are high, the associated revenue from procedural streams of care form a significant source of funding for hospitals performing elective surgery.^{3,4} Improving throughput of cases within existing budgetary constraints may represent an enormous cost-saving measure for hospitals with financial flow on effects for providers and reduced waiting lists for patients.

Time Driven Activity Based Costing (TDABC) is an integral counterpart of the process improvement initiatives taking place within the movement towards value-based healthcare that is strongly advocated by Porter and Teisberg (Harvard Business School, Institute for Strategy and Competitiveness, Boston, MA).^{5,6} TDABC, which uses time and capacity cost rates to allocate resource costs, has been proven to be the gold standard in measuring the true costs of health care delivery as described in a growing literature.^{7–13} Emphasising simplicity, TDABC

has empowered healthcare institutions and clinicians to perform their own cost projections prior to implementing process change. Process maps that accompany TDABC expedite a user-friendly construction of costs following assignment of resources to tasks and multiplication of resource cost rates with assigned process times. Personnel costs for the complex services predominant in healthcare are made more tangible, guiding important process improvements for a broad scope of clinical activities.^{14–16} In the surgical domain, several studies have investigated process improvements and cost saving measures for individual operating procedures, however investigation of entire operating lists (that is, several consecutive procedures within an allocated schedule) remains inadequately explored. The challenges lie in the inherent heterogeneity of week to week case mix and variability of resource uptake that challenges the use of fixed process maps and conventional cost analyses.^{17–19} The ability to project surgical process times across an operating list, account for resource expenditure and model surgical throughput in a convenient fashion therefore remains an elusive goal however one that would ultimately encourage throughput efficiency measures and guide scheduling of procedures to optimise costs and

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increase provision of surgical care.

A parallel induction design (or parallel processing) is one process improvement that improves operating room (theatre) efficiency by recruiting additional anesthetic personnel to induce anesthesia in adjacent induction rooms whilst the preceding surgical episode is ending. This reduces the non-operative time between consecutive surgical cases by aligning the completion of preoperative anesthetic processes with that of operating room set up such that preparations for commencement of surgery can begin close to immediately after completion of a prior surgical case.^{20–23} Parallel induction exists in contrast to a more conventional serial induction design, where operating room turnover is completed prior to a subsequent patient entering the operating room and anesthesia is then commenced at that time point. Apart from the need for appropriate induction rooms, with anesthetic machines and monitoring, a parallel induction design necessitates a second anesthetic team (anesthesiologist and nurse) for the duration of synchronous care. High-volume tertiary hospitals with anesthesia trainees and induction rooms may be able to institute a parallel induction design if additional personnel can be harnessed for targeted bursts of work. Coordination of these efforts, including appropriate operating list selection, extra nursing care, as well as economic justification for additional resource recruitment remains inadequately explored.

Seeking improved operating room efficiency on an all-day, high-turnover operating list of breast and melanoma procedures, we collected activity data for process times under a trial of parallel induction redesign. To develop personnel costs using TDABC and model procedural throughput, process time was dichotomised and integrated into a hypothetical case-mix based on historical data to account for a 'typical' operating list. We expected parallel induction redesign to project improved efficiency at minimal change in personnel costs with potential for improved case throughput at substantial relative cost benefit.

2. Methods

2.1. Developing process times following observational trial within operating rooms

Following institutional ethics committee approval (HREC No: LNR/16/PMCC/141), we allocated parallel or serial processing randomly across 19 all-day operating lists that predominantly comprised breast or melanoma procedures. The principal investigator recorded all process times in the operating room using a preconceived case report form. To facilitate modelling of our operating list, process time was dichotomised into operative and non-operative time periods. Operative time was defined from the beginning of surgical preparation until the final closure of skin and non-operative time from closure of skin until the beginning of surgical preparation. Surgical preparation comprised activities such as surgical prep and drape, which typically began at the end of the 'surgical timeout' after induction of anesthesia.

Lists were selected based on sufficient caseload (three or more cases) and the rostering of an anesthesia attending plus senior trainee (senior resident or fellow) to the same operating list. Assignment into parallel or serial induction designs occurred in a randomised fashion. Nine of these were performed using a serial induction design, with patients induced in the operating room following clean up and preparation that followed the transfer of the previous surgical case to the post-anesthesia care unit (PACU). In the other ten lists a parallel induction design was implemented, and anesthetic work for the next case began in the induction room adjacent to the operating room at or towards the end of the operating period for the preceding surgical case (Fig. 1).

Additional anesthesia time under the parallel induction design was also assessed for general anesthesia using the time difference from airway securement (airway being taped) following induction until the time of entry into the operating room. This was assessed only for lists allocated to the parallel induction design where there was no

requirement for additional anesthetic preparation post-induction (e.g. insertion of arterial lines).

2.2. Statistical analysis of non-operative time under parallel and serial induction designs

As time interval data frequently observes rightward skewed distributions, we firstly performed logarithmic transformation of non-operative time data and confirmed gaussian distribution using Shapiro-Wilk testing. Tests of significance were performed by two-tailed *t*-tests comparing mean differences of log-transformed data. All data was then back-transformed and reported as median with interquartile range.

We considered non-operative times 30 min greater than the median for the corresponding induction design to be 'prolonged' and excluded them from analysis (2 prolonged parallel turnovers; 3 prolonged serial turnovers).²⁴

2.3. Projecting operating list process improvement and assigning personnel costs using TDABC

To project the impact of our observed process times and facilitate cost analysis, we constructed a model of our all-day breast and melanoma list that we felt represented a typical weekly case-mix. Cases were grouped into short, medium and long duration categories according to surgical complexity, and a case-mix was assigned based on the average ratio of these groups over the last two years as obtained from our patient administration software platform i. Patient Manager (Computer Sciences Corporation, Tysons Corner, Virginia). This ratio comprised two short, three medium, and one long duration case with process times integrated to project variability in non-operative time based on allocation to parallel or serial induction designs.

To develop staffing costs using TDABC, we assigned time estimates of individual personnel utilisation across the operative time for different procedural categories as well as for the non-operative time under parallel and serial induction designs. This was done on the basis of our recorded process times, personal observations during our trial in operating rooms and in consultation with individual team members. Auxiliary staff including nurses, patient care assistants and ward clerks in the recovery and pre-procedural areas were not included in the analysis (Fig. 2).

Cost rates used for TDABC analysis were derived from hourly compensation data (details blinded) based on the median annual salary for designated roles and their assigned hours per week. We deducted 10–15% from this based on the percentage of average utilised annual and sick leave for corresponding roles and an additional 16% for indirect work time.¹⁰ On-costs including superannuation and workers compensation premiums were included in the analysis.

2.4. Revenue analysis of analysed procedures

Admission revenue generated from corresponding procedures was captured subsequent to coding by medical records according to the Weighted Inlier Equivalent Separation (WIES).²⁵ Given WIES values cannot be divided into components of admission (e.g. revenue related to a surgical procedure), only revenue for single day admissions was presented.

3. Results

3.1. Analysis of operative and non-operative process times

In our trial of operating room redesign we observed a median non-operative duration of 35 min under a serial model of induction, compared to 24 min under a parallel design, a 31.43% improvement (Fig. 3).

The median additional anesthetic exposure time (as assessed from

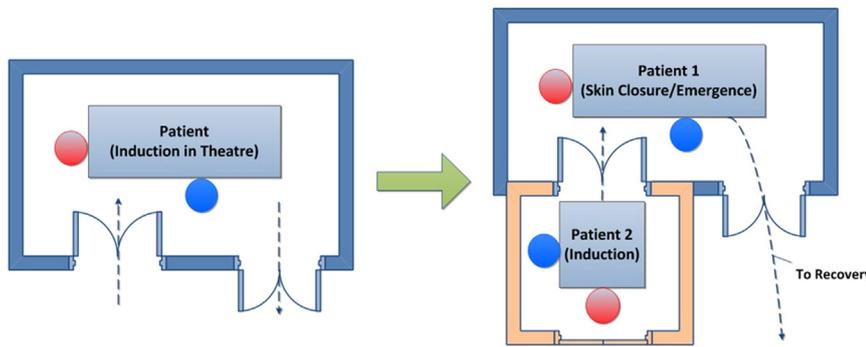


Fig. 1. Floor plan of serial induction design (left) vs. parallel induction redesign (right). In a serial induction design, anesthetic induction occurs on the operating table after operating room setup is completed. In parallel induction redesign, completion of operating room setup aligns with that of anesthetic induction such that preparations for commencement of surgery can begin immediately.

the completion of induction of anesthesia until entry into the operating room) under the parallel induction design was 8 min. Divided chronologically, the median duration was 15 min for the first fifteen attempts and 3 min for the subsequent fourteen attempts.

3.2. Cost and throughput analysis by TDABC

Using our model of a typical case-mix, we projected a 55-min reduction in non-operative time over the course of a single day under a parallel induction design compared to serial design with a total decrease in operating list time from 564 to 509 min at a \$50 premium on

Serial Induction Design

Parallel Induction Design
with an additional short duration case

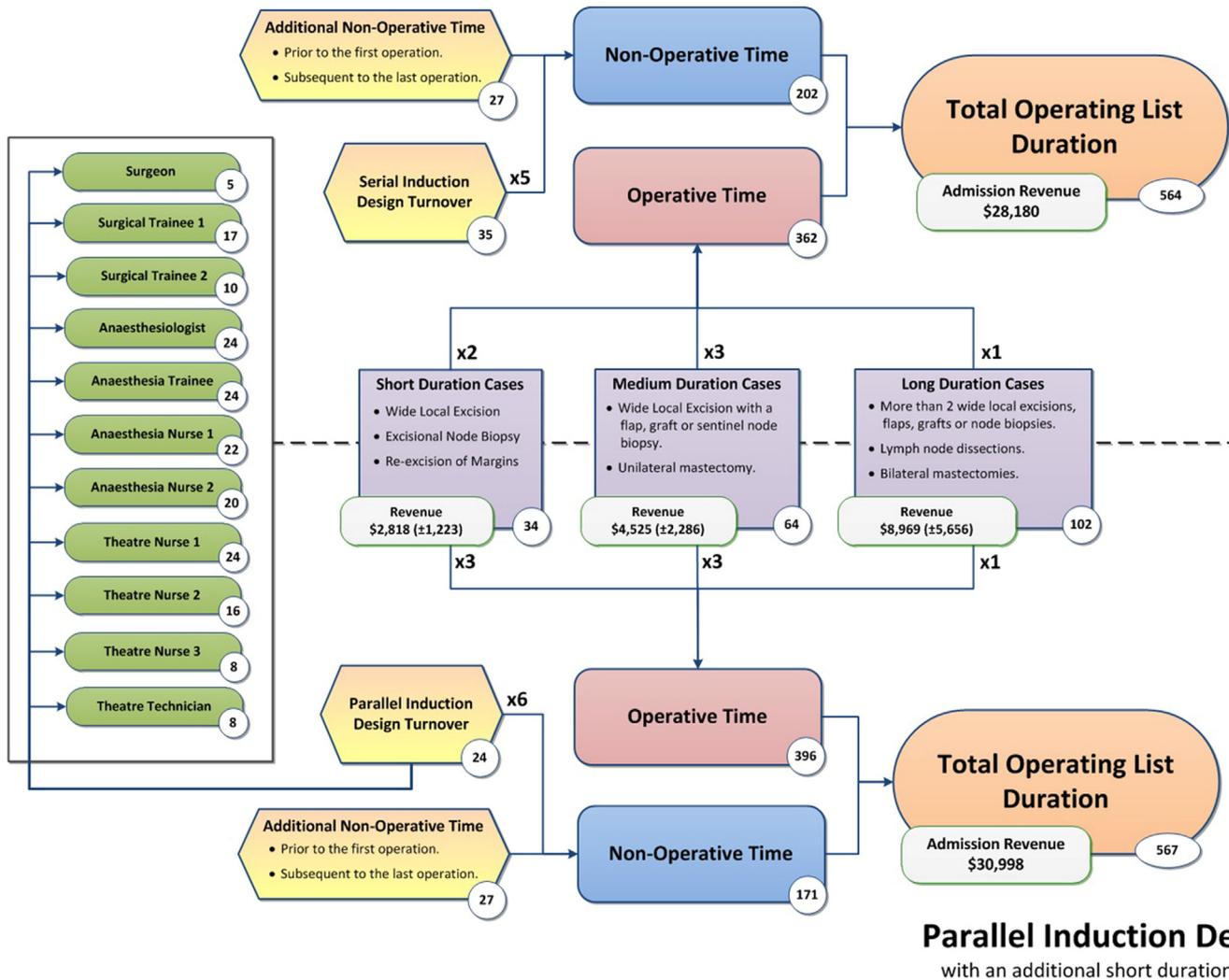


Fig. 2. Projection of operating list time and personnel costs using TDABC. Operating list time was modelled from our documented process times, procedural categorisation based on surgical complexity and the designation of a typical case-mix from historical inpatient data. Variability in non-operative time was projected from allocation to serial or parallel induction designs, with estimates of personnel utilisation assigned across these systems of induction as well as to each procedural category (demonstrated for parallel induction design). Average admission revenue captured by WIES values for single day admissions only. Pricing is shown in Australian dollars.

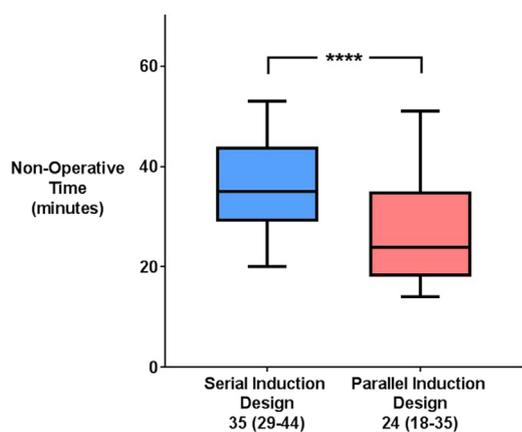


Fig. 3. Non-operative times between cases under serial (n = 31) and parallel (n = 30) induction designs (reported as median with interquartile range). The non-operative time spans from the end of surgery (when skin closure occurs and dressings are applied) to the beginning of surgical preparation as defined in the methods. Statistical analysis of mean differences was performed with multiple two-tailed t-tests following log transformation (**** = p < 0.0001).

intra-operative personnel costs (Table 1). With 61 min available, an additional short duration case such as a wide local excision (operative time 34 min; non-operative time 24 mins) could feasibly be performed under a parallel induction design. Scheduling such a case would see intraoperative personnel costs rise by \$397 compared to a serial induction design with no additional case, whilst the average revenue for a corresponding additional single day surgical case in the available time would amount to \$2818. Performed weekly, revenue return from one additional short duration case would amount to \$146,536 per annum per daily surgical list in additional hospital revenue (for example if parallel induction was applied to one operating room each working day, with a well-constructed case mix, this would contribute to an additional \$0.73 M of annual hospital revenue).

4. Discussion

Attempts to improve operating room suite (theatre) efficiency requires the capacity to model the surgical process times of a heterogeneous case-mix and relate resource costs with surgical throughput. Our activity data yielded a median 11-min reduction in non-operative time that complements the improvements in non-operative time of 23 and 24 min in two previous studies that incorporated parallel processing alongside several other efficiency improvements (serial duration: 35 IQR 29–44 min vs. parallel duration: 24 IQR 18–35 min, respectively).^{20,21} Integration of these process times into a hypothetical case-mix was used to project surgical throughput for an all-day operating list and offer feasibility for an additional short duration case following parallel induction redesign. With an increase in intraoperative personnel costs under a parallel induction design of \$50 with no additional case and \$397 with an additional case, the prospect of further case throughput represents substantial value improvement given average single day admission revenue of \$2818 per short case. With annual

return of \$0.73 M for each operating room using a parallel induction design, the addition of just one additional wide local excision of a lesion each week projects a substantial revenue return for hospitals performing elective surgery and the scalability of this is evident across all operating rooms in a surgical suite.

The increase in personnel costs under the parallel induction design came almost exclusively from additional anesthetic nursing involvement. Despite the mandated presence of both attending and resident anesthesiologist in the parallel induction design, their distribution between consecutive patients had a cost neutralising effect relative to the conventional serial design where doubling up on the same patient sometimes occurred. As this cohort comprised relatively uncomplicated procedures, the clinical need for multiple physicians per patient was rare, and whilst implications for teaching need to be considered the educational impact in this particular context was minimal. Concerns around safety were also thought to be minor given the availability of an additional anesthetic nurse and collocation of both teams between adjacent operating and induction rooms. It is feasible that more complex surgeries with extensive anesthetic preparations not observed in this study could undertake parallel induction, however this may warrant availability of even further anesthetic staff with more conservative start times for commencement of anesthetic preparations. Irrespective of support on hand, the clinical suitability for each parallel turnover and appropriate timing of induction requires executive decision making by an anesthesiologist familiarised with parallel processing such that it does not come at risk of impaired patient safety.

The personnel requirements under parallel induction design favours the tertiary hospital setting where multiple doctors are present on anesthetic and surgical teams. Not only does this assist the induction process in the case of anesthetic teams, but in the case of surgical teams allows one member to unscrub during skin closure to greet, consent, and site mark the patient prior to induction commencing if this has not already occurred. For additional nursing requirements, a hybrid turnover nurse who assists with anesthetic duties during emergence and then turnover of the operating room is one solution that would come at additional expense to hospitals but could also help transition nurses between theatre and anesthetic roles and improve lax in staffing to prevent operating list cancellation when nursing shortages arise. Alternatively, at no additional expense an anesthetic nurse assigned to post-operative care unit (PACU) duties could relieve the existing anesthetic nurse to commence parallel induction of the subsequent surgical case and assist in the emergence phase of the preceding patient. Our reduction in additional anesthetic exposure (median time from completion of induction to entry into the operating room) over time speaks to a learning process with the parallel induction design and the need for familiarity by a critical mass of the nursing, anesthetic and surgical staff involved.

Combining the process times of different procedures to project a continuous operating list duration carries inherent uncertainty however this reflects the reality of scheduling an operating list of heterogeneous procedures with variable durations. The ability to receive prospective feedback on measures such as costs, case throughput and revenue represents an important step in improving allocation of procedures to operating lists, guiding process improvements that benefit efficiency and delivering value-based surgical care. The rigour of our approach

Table 1

Projection of operating list time, associated personnel costs using TDABC, and corresponding admission revenue. Comparison made between serial induction design and parallel induction design with or without an additional short duration case. Revenue based on WIES coding for cases with a one-day length of stay.

| | Serial Design | Parallel Design | Change serial to parallel | Parallel Design + extra short case | Change serial to parallel + extra case |
|---------------------------------|---------------|-----------------|---------------------------|------------------------------------|----------------------------------------|
| Non-Operative Personnel Costs | \$ 845 | \$ 895 | + \$ 50 (5.7%) | + 1055 | + \$ 209 (25%) |
| Total Operating List Time | 564 min | 509 min | - 55 min (9.8%) | 567 min | + 3 min (0.53%) |
| Total Operating Personnel Costs | \$ 3086 | \$ 3136 | + \$ 50 (1.6%) | \$ 3324 | + \$ 397 (13%) |
| Revenue (\$ AUD) | \$ 28,180 | \$ 28,180 | \$ 0 | \$ 30,998 | + \$ 2818 |

can be significantly improved by incorporating larger and more reliable data sets for process times either by way of activity data found on perioperative nursing charts or more accurate estimates for procedural durations such as through predictive algorithms or linear regression modelling.^{26,27} In addition to this, inclusion of costs for anesthetic machines and more broadly other costs in the pre and post-operative phases of care may more accurately delineate altered resource utilisation under a parallel induction design and improve correspondence with the expected admission revenue.

5. Conclusion

Improvements to efficiency in operating rooms are an opportunity for hospitals to optimise revenue and reduce surgical waiting lists within existing budgetary confines. By combining surgical process times to model an operating list of multiple minor procedures we have facilitated application of costs using TDABC alongside projections of case throughput and admission revenue. Application of this system to assess value improvement of parallel induction redesign demonstrates an all-day operating list of small to moderate procedures such as breast and melanoma surgery can significantly increase efficiency at minimal expense for additional resources, generating substantial economic value for healthcare providers. Such measures are needed to promote the value-driven healthcare proposition and alleviate global pressure for increased surgical capacity.

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Ethics approval details

Peter MacCallum Project No: 16/99LAU RED HREC Reference No: LNR/16/PMCC/141.

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