Scaling Performance Frontiers Across Multiple Perioperative Services

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Research Article

Keywords: Performance Frontiers, Operating Room Management, Operating Room Efficiency, Pareto Fronts

Posted Date: September 18th, 2023

DOI: https://doi.org/10.21203/rs.3.rs-3336028/v1

Abstract

Background: One of the primary principles governing operating room management includes maximizing clinical efficiency and optimizing the time used in the high-cost, high-revenue environments represented by operating rooms. Under-utilized and over-utilized times are elementary metrics that describe the operating room performance. Performance frontiers visualize the maximal efficiency of systems and their existing constraints.

Methods: Monthly aggregated operating room metrics from services at the University of Vermont Medical Center (UVM), Stanford Hospital, and the University of Alabama (UAB) at Birmingham Hospital were extracted. Paired under- and over-utilized times were plotted against each other. Performance frontiers representing the optimal performance of each service were overlaid.

Results: The Kolmogorov-Smirnov test for goodness-of-fit at 95% level of significance confirms that the performance frontiers representing UVM and Stanford (K-S = 0.9507, $p < 0.0001$), UVM and UAB (K-S = 0.9989, $p < 0.0001$), and Stanford and UAB (K-S = 0.9773, $p < 0.0001$), indicating each service is represented by a different performance frontier.

Conclusions: Our analysis shows that the performance frontier defining the optimal efficiency of UVM is more efficient than that of Stanford and UAB. Differences in efficiency must be due in part to organizational differences between institutions, limited in scale due to the size of institutions; normative statements must be made in relation to the existing organizational structures of each institution and their specific capacity to make changes in tactical decisions. Systemic interventions should be implemented via qualitative analysis of more efficient services, defined by the relative positioning of relevant performance frontiers.

INTRODUCTION

Mahajan et al. noted that perioperative systems behave like complex adaptive systems [1]. Today, much of the current literature related to operating room management is based upon the assumption that operating rooms resemble manufacturing plants, whereby lean manufacturing and six sigma approaches generate value by reducing variability in clinical processes and minimizing inefficiencies [2]. Similarly, Wong et al. demonstrated that acute care surgical services exhibit the power law, whereby one variable increases as systems grow larger and more complex [3]. In Koffka's words, "The whole is something more than the parts."

Operating room metrics such as under-utilized time and over-utilized time must be considered in analyses that seek to determine the efficiency of operating room management. Under optimal conditions, the most efficient operating room represented by these metrics would function with no under-utilized time and no over-utilized time [4]. In other words, the primary goal of operating room management is to minimize both under-utilized and over-utilized time. With this analytical, reductionist approach, complex parts are reduced to smaller components. Under the current paradigms, OR management metrics may fail to capture the underlying complexity of perioperative systems.

In Thinking In Systems, Meadows urges the reader to understand, “What is the system trying to achieve?” Operating rooms represent high-cost, high-revenue environments whose behaviors are decided by the interacting decisions and performance of surgeons, anesthesiologists, and OR management [1]. Although perioperative service laborers and operating room managers approach OR block allocations with different incentives [5], tactical decisions shape the initial conditions under which the interacting agents, especially clinical directors, manage their operational decisions [6, 7]. In the absence of specific management guidelines mandating otherwise, clinicians may default to an intuitive, but economically suboptimal heuristic of increasing clinical work per unit time of individual ORs [8]. The current lack of data driven heuristic necessitates a tool from which either clinicians can directly draw the correct managerial decision or clinical directors may preemptively make tactical decisions that produce efficient managerial outcomes.

Previously, performance frontiers have been used to model the operational implications of changing release times, benchmark different anesthesia environments, assess the impact of Acute Care Surgery tactical allocation, and make recommendations concerning tactical decisions in operating room management [9, 10]. Presumably, by visualizing OR management metrics along two axes, clinical directors and hospital administrative are able to compare before and after scenarios and make normative claims about their future operation [11, 12]. Again performance frontiers reflect the empirical nature of operating room function to resist this goal. When viewed on the graph, this tendency is seen clearly – as one metric nears zero, the other approaches infinity. Importantly, when it comes to comparisons, it stands to reason that a performance frontier nearing zero on both axes represents a more efficient service than one that is further on either axis.

For OR management, performance frontiers represent the theoretical boundaries of optimal performance that can be achieved by a service given a set of initial tactical conditions. In this study, we apply performance frontiers to operating room data from three academic centers. By visualizing the differences, we build on the argument that perioperative services are complex adaptive systems and that organizations need to adopt different strategic, tactical, and operational management frameworks that address their specific operational needs.

METHODS

The study was approved by the appropriate Institutional Review Board (IRB), and the requirement for written informed consent was waived by the IRB (CHRMS 17–0051).

The following monthly aggregated OR management metrics were extracted from two institutions (UVM, Stanford) using WiseOR® (Palo Alto, CA) and one institution (UAB) using the Anesthesia Dashboard platform:

1. After Hours minutes: Operative time utilized by a service after hours (17:30 to 7:30 Monday to Friday at UVM; 17:00 to 7:00 at Stanford, 15:00 to 07:00 at UAB).
2. Opportunity Unused minutes: Available operative time within respective service block allocations where services can perform additional cases but did not.
3. Non-Opportunity Unused minutes: Available operative time within respective service block allocations in which additional cases cannot be performed based on median case times.

Under-utilized time and over-utilized time were then calculated as follows:

1. Under-utilized time = (Opportunity Unused minutes) + (Non-Opportunity Unused minutes)
2. Over-utilized time = After Hours minutes

The methodology for visualizing and analyzing multi-objective optimization using performance frontiers was described previously and is followed here [10]. Performance frontiers representing the operational efficiency of each institution were built in GraphPad Prism 9 (San Diego, CA). Monthly aggregates of over-utilized time and under-utilized time as defined above were plotted against each other; each data point plotted represents one month of aggregated data. Monthly aggregated data provides the two dual benefit of clear data visualization (daily and weekly data often produces data points that lie directly on the graph axes) and reduction of day-to-day variance contained within a specific perioperative service. Performance frontiers were estimated and represented by the line $Y = C/X$, where Y is represented by the under-utilized time, X is represented by the over-utilized time, and the constant C is represented by the minimum values for each respective value in the equation $C = XY$. All data and calculations were maintained in Microsoft Excel (Redmond, WA).

A one-way ANOVA was performed to determine the impact of each institution on under-utilized time. The Kolmogorov-Smirnov test for goodness of fit at 95% significance level was performed to compare the performance frontiers generated from the data representing the monthly over-utilized and under-utilized data from each institution. Statistical analysis was performed in GraphPad Prism 9.

RESULTS

95, 68, and 80 pairs of over-utilized and under-utilized data points were gathered and plotted for the UVMMC, Stanford, and UAB services, respectively representing data from the available months ranging from January 2010 to November 2019. The non-equivalent number of pairs between institutions is a result of the first data point being available later at the relevant institution.

In the two-dimensional space of Fig. 1, the performance frontier representing the UVMMC data lies closer to the origin than the performance frontiers representing both the Stanford and UAB data. The performance frontier representing the Stanford data lies closer to the origin than the performance frontier representing the UAB data. Therefore, the performance frontier defining the efficiency of UVMMC is more efficient than the performance frontier defining the efficiency of Stanford, which is more efficient than the performance frontier defining the efficiency of UAB. The optimal Pareto front for the UVMMC data reflects the relative proximity of individual monthly data points to the origin.

A one-way ANOVA was performed to compare the relationship between over-utilized time and under-utilized time at each institution. The statistical test revealed that there was a statistically significant difference in mean under-utilized time between at least two groups ($F(2, 240) = [3287]$, $p < 0.0001$). The Kolmogorov-Smirnov test for goodness-of-fit at 95% level of significance confirms that the performance frontiers representing UVM and Stanford (K-S = 0.9507, $p < 0.0001$), UVM and UAB (K-S = 0.9989, $p < 0.0001$), and Stanford and UAB (K-S = 0.9773, $p < 0.0001$) are distinct. The null hypothesis – that there is no difference between the generated performance frontiers – must be rejected ($p < 0.05$). Each performance frontier represents a separate and unique service; the performance frontiers analyzed here are unambiguously stratified (i.e. there is no crossing over at any point in each curve) and therefore can be directly compared by visual analysis.

DISCUSSION

In this study, we apply one of the explicit purposes of developing analytic tools to monitor and elucidate the operational efficiency of perioperative services. We determined that the performance frontier defining the efficiency of UVMMC is more efficient than the performance frontiers defining the efficiency of Stanford Hospital and UAB Hospital (Fig. 1). Taken altogether, the results obtained here and external readings confirm the intuitive thought that as institutions increase in size (and complexity), the accuracy of tactical decisions decreases. As a result, clinical directors must more correctly predict the tactical block allocations– the assumption made here that the set of decisions creating the most efficient operating room constitutes such a set of correct decisions –to achieve operational efficiency. The question persists – what choices lead to operating room efficiency? As it stands, this determination relies not only on theoretical frameworks, but also the practice of operating room management. For now, normative decisions must rely on the judgment of clinical directors who intuitively understand complex systems and the myriad of interacting agents and processes component. Although performance frontier analyses, in its primitive infancy, must be applied post hoc to determine the efficacy of those changes, the results of those analyses then inform future changes until a robust set of institutional set of guidelines can be established.

There are several explanations for study's results. First, UVMMC is a smaller institution with lower capacity than the other institutions. As the capacity for an institution increases, the absolute values for over-utilized time and under-utilized time will increase. As a result, the performance frontiers for the larger institutions will naturally trend towards lower optimization. Second, the patient volume at UVMMC is also lower. Here, operational objectives may be achieved with less interference because fewer physical and labor resources need to be expended to complete tasks, contributing to a down- and left-ward shift in the performance frontier. Third, differing patient populations and surgical case mix may contribute to different performance frontiers. As health care systems continue consolidate and adopt capacity-based service models, then it stands to reason that over-utilized time, at least, should be more likely [13].

With performance frontiers, tactical and operational optimization of a perioperative service becomes a trade-off between under- and over-utilized time, which represents fixed and variable costs, respectively. In retrospect, Strum perfectly described OR efficiency when he demonstrated that operational performance is a cost minimization analysis [14]. Organizational differences in perioperative services between institutions may be compared to then make normative statements regarding optimal resource utilization. Ideally, a dialectical analysis of the trade-offs at play would result in the ability to adjust demand patterns, staffing concerns, and inventory issues, among other considerations of normal operating room function, and model or replicate the specific aspects of operating room management that lead to a more optimal service. The results from this current study demonstrate that these approaches are potential limits to the ability to create operational efficiencies as perioperative services increase in size.

Previous research has demonstrated that performance frontiers can differentiate various specialties and capacity-based services. Haimes et al. argued that the block allocations for orthopedic trauma services should be 24 hours, not 8, 10, or 12 hours [15]. Similarly, Tsai et al. showed that mixed inpatient services, outpatient ambulatory, and non-operating room anesthesia service lines have different performance frontiers [16]. These insights inform how operations should be managed. For example, hospital administrators should stray from modeling mixed-inpatient settings when possible as they are the most inefficient [17]. When hospitals resemble mixed inpatient/ambulatory settings, administrators should decide to make tactical decisions that model the frameworks provided by ambulatory surgical centers and direct some of the mixed inpatient workload to ambulatory centers. When hospitals resemble NORA services, they should aim to fill the excess time not being utilized by provided staffing. Overall, the synthesis of these lessons gives credence to a heuristic for changes necessary in management tactics – operating room managers should create different lanes to manage each service under their purview, fine-tune the available ambulatory processes that help streamline the services, and adding resources to increase throughput.

Current quantitative metrics (e.g. first case on-time starts, tardiness, turnover times, OR utilization) are predicated on benchmarks and comparison rates. The fallacy of this framework is simply that an average utilization rate has little bearing on fixed and variable costs – meeting an institutional metric or national benchmark does not necessarily translate into a profit. Different institutions, specialties, and teams must employ variable management strategies that address the material conditions of their operational contexts, but the question of efficiency can expand to include a variety of metrics such as start-time tardiness, turnover time, and staffing costs [18], further complicated by the reality that institutions and literature often employ different definitions of these indicators [19]. Reconciling the differences between the performance frontiers of comparable teams may provide insight into what organizational structures lead to more efficient operating room schedules.

Again, performance frontiers can be used in comparative analyses of multiple institutions in operating room management. Although a wide variety of metrics contributing to operating room performance may exist, a targeted approach in which relevant metrics are adjusted for study followed by evaluation of impact on the breadth of metrics for operating room performance; performance frontiers are perfectly suited for this manner of multi-objective data visualization [20]. Further, different perioperative services can understand the limitations to their own operations, and perhaps, consider redesigning them rather than aiming to meet the minimal standard of an OR management metric. In short, performance frontiers support a resource-based view of the perioperative services, reflecting the nature of objective measurements to increase and decrease in response to other metrics in the same system.

To further elucidate the differences between specific institutions, qualitative studies involving management and labor forces involved in the perioperative services must be conducted. From an organizational development perspective, it might behoove perioperative service leaders to create smaller, more agile teams [21, 22]. As human organizations grow larger, Dunbar et al. demonstrated that groups larger than 150 tend to be less cohesive and collaborative [23]. Although there might be less than 150 individuals working in the perioperative services each day at large health care systems (e.g., UAB and Stanford), typically more than 150 individuals are involved in the overall delivery of surgical care, which may contribute to inefficient organizational outcomes. Similarly, building larger, more expansive ORs to minimize the costs of shared infrastructure (e.g., central sterilization, supply chain, pharmacy, radiology), might actually make perioperative services less efficient because of the increasing distances health care providers need to cover to move patients and materials through the system.

Our current study presents several limitations. First, we recognize a present inability to normalize the analysis between large and small institutions. Future analyses may consider normalizing over-utilized times and under-utilized times to the number of operating rooms in function in order to tease out details beyond institution size. Second, our analysis is limited to two operating room metrics; expanding the analysis to include metrics such as turnover time and/or pure productivity metrics such as Relative Value Units may reveal different results and provide further insight into the tactical decision-making necessary to optimize operating room management. Third, the study does not account for any major or minor tactical changes that occur during the time for which data was collected; these changes, although unlikely, may change the performance frontiers and conclusions drawn from the study should their impact be significant. Similarly, the data procured for the study can only represent the operational environment of each institution as they were, despite currently unidentified inefficiencies contributing to unaccounted differences in what under-utilized and over-utilized data represent between each dataset; again, expanding the analysis may help to address this concern as more details and variables are examined. More specific analysis accounting for case diversity, acuity, emergent cases, schedule changes, staffing ratios, and others may be conducted. Moving forward, we expect to expand the analysis to cover more institutions. As more macro-data points are analyzed, clearer delineations for normative judgments should arise.

This study serves as an initial foray into comparative analyses using performance frontiers, which may be expanded to a multi-objective framework that includes the breadth of indicators in the future. The inherent difference in operational efficiencies implies that there might be a limit to scale for organizations with large perioperative services. Future studies should elucidate these limits. In other words, hospital administrators and clinical directors will need to design different organizational systems as health care systems continue to consolidate.

Declarations

Accepted as an abstract presentation for the International Anesthesia Research Society 2022 Annual Meeting, Honolulu HI

Clinical Trial Number and Registry URL: Not applicable.

Prior Presentations: Accepted as an abstract presentation for the International Anesthesia Research Society 2022 Annual Meeting, Honolulu HI

Acknowledgments: Not applicable.

Funding Statement: None

Conflicts of Interest: None

Data Availability Statement: Data used in this study is not available for the public secondary to the data use agreements between institutions.

Author Contributions: EZ helped design the study, prepare the manuscript, and provide critical edits. RS helped design the study and provided critical edits. SS provided critical edits to the manuscript. JH provided UAB's contribution of data and provided critical edits to the manuscript. AE helped with data analysis and visualization. MT helped design the study, prepare the manuscript, and provide critical edits.

References

1. Mahajan A, Islam SD, Schwartz MJ, Cannesson M. A Hospital Is Not Just a Factory, but a Complex Adaptive System-Implications for Perioperative Care. Anesth Analg. 2017;125(1):333–341.
2. Schroeder RG, Linderman K, Liedtke C, Choo AS. Six sigma: Definition and underlying theory. J Oper Manag. 2007;26(4):536–554
3. Wong T, Zhang EJ, Elhajj AJ, et al. The Power Law in Operating Room Management. J Med Syst. 2021;45(10):92.
4. Strum DP, Vargas LG, May JH, Bashein G. Surgical suite utilization and capacity planning: a minimal cost analysis model. J Med Syst. 1997;21(5):309–322.
5. Tan J, Wen HJ, Awad N. Health care and services delivery systems as complex adaptive systems. Commun ACM. 2005;48(5):36–44

6. Wachtel RE, Dexter F. Tactical increases in operating room block time for capacity planning should not be based on utilization. Anesth Analg. 2008;106(1):.
7. McIntosh C, Dexter F, Epstein RH. The impact of service-specific staffing, case scheduling, turnovers, and first-case starts on anesthesia group and operating room productivity: a tutorial using data from an Australian hospital. Anesth Analg. 2006;103(6):1499–1516.
8. Dexter F, Wachtel RE. Strategies for net cost reductions with the expanded role and expertise of anesthesiologists in the perioperative surgical home. Anesth Analg. 2014;118(5):1062–1071.
9. Elhajj AJ, Rizzo DM, An GC, Pandit JJ, Tsai MH. Monitoring Perioperative Services Using 3D Multi-Objective Performance Frontiers. J Med Syst. 2021;45(3):34. Published 2021 Feb 6.
10. Tsai MH, Breidenstein MW, Flanagan TF, et al. Applying Performance Frontiers in Operating Room Management: A Tutorial Using Data From an Academic Medical Center. A A Pract. 2018;11(11):321–327.
11. Pandit JJ, Westbury S, Pandit M. The concept of surgical operating list 'efficiency': a formula to describe the term. Anaesthesia. 2007;62(9):895–903.
12. Pandit JJ, Stubbs D, Pandit M. Measuring the quantitative performance of surgical operating lists: theoretical modelling of 'productive potential' and 'efficiency'. Anaesthesia. 2009;64(5):473–486.
13. Tsai MH, Kimatian SJ, Duguay JR, Tanniru MR, Sarraf E, Hudson ME. Rethinking Operating Room Management: Why Clinical Directors Should Embrace Complexity. Anesth Analg. 2020;131(3):984–988.
14. Strum DP, Vargas LG, May JH. Surgical subspecialty block utilization and capacity planning: a minimal cost analysis model. Anesthesiology. 1999;90(4):1176–1185.
15. Haimes MA, Watkins CL, Tan DW, Schottel PC, Bartlett CS, Tsai MH. A dedicated orthopaedic trauma room increases operating room throughput without increasing after-hours minutes. Perioper Care Oper Room Manag. 2020;20:100108.
16. Schottel PC, Haimes MA, Sexton KW, Burgess AR, Breidenstein MW, Tsai MH. Using performance frontiers differentiates orthopaedic subspecialties. J Clin Anesth. 2021;75:110485.
17. Tsai MH, Breidenstein MW, Flanagan TF, et al. Applying performance frontiers in operating room management. A&A Pract. 2018;11(11):321–327.
18. Macario A. Are your hospital operating rooms "efficient"? A scoring system with eight performance indicators. Anesthesiology. 2006;105(2):237–240.
19. Fixler T, Wright JG. Identification and use of operating room efficiency indicators: the problem of definition. Can J Surg. 2013;56(4):224–226.
20. Schouten AM, Flipse SM, van Nieuwenhuizen KE, Jansen FW, van der Eijk AC, van den Dobbelsteen JJ. Operating Room Performance Optimization Metrics: a Systematic Review. J Med Syst. 2023;47(1):19.
21. Edmondson AC. *Teamwork on the fly*. Harvard Business Review. https://hbr.org/2012/04/teamwork-on-the-fly-2. Published February 7, 2020. Accessed October 2, 2022.

22. Rigby DK, Sutherland J, Takeuchi H. Embracing Agile. Harvard Business Review. https://hbr.org/2016/05/embracing-agile. Published August 27, 2021. Accessed October 2, 2022.
23. Dunbar RIM. Neocortex size as a constraint on group size in primates. J. Hum. Evol. 1992;22(6):469–493.

Figures

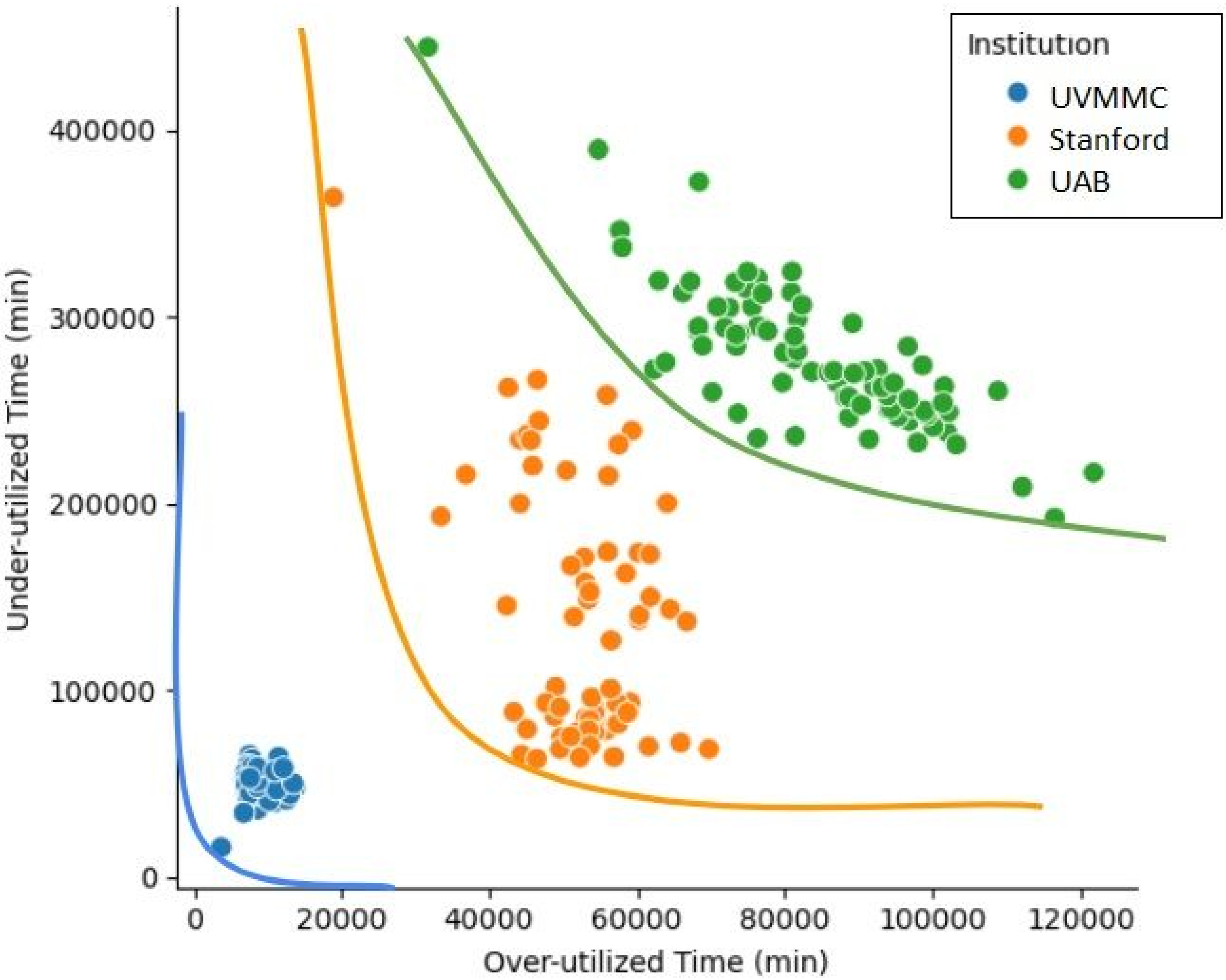

Figure 1

Monthly aggregates of over-utilized and under-utilized times at UVMMC, Stanford, and UAB. Each point represents one paired point of monthly aggregate data. Performance frontiers representing the paired over-utilized and under-utilized times are overlaid across each institution.