Reducing Postponements of Elective Pediatric Cardiac Procedures: Analysis and Implementation of a Discrete Event Simulation Model

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Background. **This study describes the use of discrete event simulation (DES) to model and analyze a large academic pediatric and test cardiac center. The objective was to identify a strategy, and to predict and test the effectiveness of that strategy, to minimize the number of elective cardiac procedures that are postponed because of a lack of available cardiac intensive care unit (CICU) capacity.**

Methods. **A DES of the cardiac center at The Children's Hospital of Philadelphia was developed and was validated by use of 1 year of deidentified administrative patient data. The model was then used to analyze strategies for reducing postponements of cases requiring CICU care through improved scheduling of multipurpose space. Each of five alternative scenarios was simulated for ten independent 1-year runs.**

Results. **Reductions in simulated elective procedure postponements were found when a multipurpose procedure room (the hybrid room) was used for operations on Wednesday and Thursday, compared with Friday (as was the real-world use). The reduction Wednesday was statistically significant, with postponements dropping from 27.8 to 23.3 annually (95% confidence interval 18.8–27.8). Thus, we anticipate a relative reduction in postponements of 16.2%. Since the implementation, there have been two postponements from July 1 to November 21, 2014, compared with ten for the same time period in 2013.**

Conclusions. **Simulation allows us to test planned changes in complex environments, including pediatric cardiac care. Reduction in postponements of cardiac procedures requiring CICU care is predicted through reshuffling schedules of existing multipurpose capacity, and these reductions appear to be achievable in the real world after implementation.**

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Providing timely medical care and appropriate recovery facilities is paramount in any healthcare setting. Unfortunately, many factors combine to restrict intensive care unit (ICU) capacity [1]. When an ICU is full, planned elective procedures may be postponed because an appropriate recovery bed is not available. Although various methods, such as ring fencing (separating elective and emergent patient streams into parallel processes) have shown promise to improve efficiency [2], the optimal means of exploiting limited resources within a dedicated self-contained pediatric cardiac (operative) facility remains unknown. In the current investigation, we used discrete event simulation (DES) to explore facilities management, with the goal of minimizing the postponement of elective procedures resulting from limited ICU capacity. DES has been deployed widely in healthcare, including surgical ICU capacity planning, where work by Troy and Rosenberg [3] demonstrated how functional ICU capacity affected surgical cancellations. The authors called for the need to "synchronize demand with supply" when surgical procedures requiring an ICU stay are scheduled. In this investigation, we expanded on that work by using DES to determine how to manage demand and to minimize elective procedure postponements in a pediatric cardiac operative and imaging complex integrated in a fixed inpatient bed footprint. This allowed us the ability to study the entire perioperative cardiac flow from patient arrival through procedure, magnetic resonance imaging, inpatient stay, and discharge.

Material and Methods

The Cardiac Center at The Children's Hospital of Philadelphia (CHOP) consists of 62 contiguous beds in three integrated yet separate units: the Cardiac Preparation and Recovery Unit (CPRU), the Cardiac Intensive Care Unit (CICU), and the Cardiac Care Unit (the CCU) adjacent to a Cardiac Operative and Imaging Complex (COIC). The CPRU consists of 13 beds, of which three are licensed for 23-hour patient stays and ten are used for preprocedure

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and postprocedure care for children with congenital heart disease having cardiac and noncardiac operations and catheter procedures. The CICU is a 26-bed intensive care unit, and the CCU is a 25-bed step-down unit. The COIC is composed of two dedicated cardiac operating rooms, two cardiac catheterization/electrophysiology (EP) laboratories (cathlabs), a hybrid suite capable of serving as either an operating room or a cathlab, and a magnetic resonance imaging machine, which is connected to one of the cathlabs by a track system.

The Cardiac Center performs between 500 and 575 open heart operations, an additional 300 to 350 closed cardiac procedures, and approximately 1,200 cardiac catheter procedures annually. In addition to serving this patient population, the CPRU, CICU, and CCU serve respectively as perioperative, intensive care, and step-down facilities for cardiac patients who require other diagnostic or interventional procedures or who are admitted for medical reasons. The Cardiac Center also receives neonates with significant congenital heart disease delivered in the Special Delivery Unit located adjacent to the Center.

Scheduling the large volume of patients needing elective operations, catheterization, and imaging while accommodating children requiring urgent or emergent procedures within this fixed framework is challenging. Indeed, surgical scheduling in general is a broad and open area of research [4, 5]. Although the Cardiac Center's goal is to serve all patients requiring elective procedures on the date selected by the child's providers and family, congestion within the CICU, where the majority of patients undergoing elective surgical procedures require a recovery bed, has resulted in the need to postpone and reschedule an increasing number of elective procedures. Management of system resources to minimize surgical postponements is complex, and significant barriers to quality improvement efforts exist. First and foremost, it was desired to identify a promising strategy for improvement without placing any patients at risk of increased delays and without incurring significant costs and disruptions associated with testing candidate strategies in the real world. Therefore, it was decided to use computer modeling of the Cardiac Center to identify, test, and select candidates for improvement. DES has been used in numerous health care environments to study process and policy interventions, including oncology [6], imaging [7], emergency [8], neurology and gynecology [9], and elsewhere [10].

Objective

The goal of this investigation was to determine by how much the number of postponed surgical procedures could be diminished through improved use of the hybrid room, or increased observational bed space. Before this investigation, the hybrid room was dedicated to cardiac catheter procedures on Monday, Tuesday, and Thursday. On Wednesday, the hybrid room was used for EP procedures, including pacemaker/implantable cardioverter defibrillator (ICD) implantation and lead extractions. On Friday, the hybrid room was outfitted as an operating room. Specifically, we used DES of the Cardiac Center to test alternative schedules—while holding the total number of days dedicated to each service constant—for the hybrid room and examined the effect of those changes on the number of postponed surgical procedures on an annual basis. We included, for comparison, analysis of increasing 23-hour observational bed space on the annual postponement rate.

The Cardiac Center was modeled by the use of DES, a computer simulation method using a graphic interface that allowed us to create a detailed, dynamic representation of the system and subject it to prospective experimentation. The model was developed and validated according to best practices established by the Society for Medical Decision Making's Good Research Practices Task Force [11, 12], and it was declared exempt from review by The Children's Hospital of Philadelphia's Institutional Review Board. Flow for the model was developed by observation and interview of the system processes and is shown in Figure 1. The model was informed with 1 year of deidentified patient data from fiscal year (FY) 2013, from which probability density functions for arrival rates, lengths of stay, and types of procedure were abstracted. The model was validated by presentation to COIC staff, thorough code review, and comparison of output metrics (daily census in the CICU, CCU, and CPRU; annual postponements.) between real-world and simulated values.

To conduct our analysis of the use of the hybrid room, the validated model representing current practice (with the hybrid room used for operations on Friday) was executed for ten independent 1-year simulations (or ten "runs"), to represent our control. The first 30 days of simulated data were discarded, for simulation "warm-up," in accordance with best practices [12]. Then, use of the hybrid room was modified to allow operations on each other day of the week, by holding all other simulated factors constant except the hybrid room status. Thus, there were four experimental arms, each with hybrid room operations on a different day of the week, by swapping, for example, Monday and Friday use of the hybrid room. For each of the four scenarios, ten 1-year runs with the first 30 days discarded were generated, to compare with the control. We chose ten runs to produce a large and useful volume of data (each run representing roughly 1,900 patients) while resisting overpowered analysis. This minimized the risk that we would find statistically significant effects whose effect sizes were not clinically or operationally relevant.

Additionally, we conducted an analysis of the effect of increasing the number of 23-hour observational beds from three to four, using identical outcome metrics and experimental designs. For the control and experimental scenarios, the number of annual surgical postponements was generated. This represented our primary metric of interest in evaluating this scenario: Does the scenario enable us to serve the same number of arriving patients while reducing the expected number of postponements? Mean annual postponements between runs were compared by use of the 95% confidence interval test for significance.