Automation Improves Schedule Quality and Increases Scheduling Efficiency for Residents

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INTRODUCTION

Medical residents have unique and complex scheduling needs related to their training. Residents must abide by the Accreditation Council for Graduate Medical Education (ACGME) work-hour restrictions, which include guidelines regarding days off, time between shifts, and more. There are also hospital- and program-specific rules governing schedules, and residents' personal preferences for days off and vacation. Designing a schedule by hand which addresses all of these factors is time-consuming and error-prone. Without assistance, it is difficult to achieve even a feasible schedule, here defined as one that satisfies all strict requirements.

Yet a poor-quality resident shift schedule can yield negative consequences for both patients and staff. Uneven shift distributions result in poor morale, raising the risk for resident burnout. Additionally, fluctuations in scheduled sleep periods force residents to work against their circadian rhythms, lowering the magnitude of physiological factors related to wakefulness and contributing to resident fatigue.[1] Fatigue is a profound problem in residency programs. It depresses fine-motor skills and cognition,[2-5] endangering patient care. Furthermore, residents experiencing excessive fatigue have an increased risk of negative heath events, including motor vehicle accidents.[6-8] By increasing resident fatigue, poor scheduling therefore places the hospital at risk for both diminished patient care and adverse health events for residents.

Smarter scheduling must be explored. Residency programs would benefit substantially from computerized assistance, using a systems-based approach to generate high-quality schedules. This is particularly so in environments staffed by multiple residency programs: for example, the pediatric emergency department (ED) is staffed by residents from pediatrics, family medicine, and emergency medicine. Each group has unique educational goals and out-of-hospital program requirements that must be incorporated. To address these challenges, the pediatric ED of the University of Michigan C.S. Mott Children's Hospital collaborated with the Center for Healthcare Engineering and Patient Safety at the University of Michigan's College of Engineering. A computerized scheduling tool was developed: the Optimized Residency Scheduling Assistant (ORSA).

ORSA is a unique addition to the world of medical shift scheduling. Most tools optimize one parameter of a schedule, such as shift preference or cost.[9-12] However, multiple important criteria often exist in resident scheduling, and a multi-criteria function is more appropriate. Additionally, relationships between criteria are difficult for schedulers to quantify and often change from month to month; an unchanging mathematically "optimal" solution may not exist.[13] ORSA was built to allow the user to adjust several scheduling metrics according to current needs.

METHODS

The scheduling tool was comprised of an integer programming model. Decision variables reflected whether to assign a particular resident to a particular shift on a particular day. One such variable was defined for each resident/shift/day combination. Mathematical constraints then enforced scheduling rules and relationships; for example, a constraint enforced that residents must have at least ten hours off between consecutive shifts. The system was implemented and solved using C++ with IBM's CPLEX API v12.1 on a computer with an Intel Xeon 3.20 GHz processor and 8 GB of memory.

To begin, ORSA received a list of the month's residents, each resident's number of weeks in the ED, outside educational requirements, and requested days off. The program then automatically generated a feasible schedule. The scheduler reviewed the schedule to identify undesirable characteristics, then specified additional requests for ORSA to incorporate. It either identified a new schedule that met the additional requests or guaranteed that no such schedule existed. One to two hours was spent per month iteratively adding requests and generating new schedules.

Resident schedules from the C.S. Mott Children's Hospital pediatric ED were reviewed, focusing on July 2010 through June 2011 and from July 2012 through June 2013 (the 2010-2011 and 2012-2013 academic years, respectively). The 2010-2011 year was the most recent year that the schedule was constructed completely by hand and the 2012-2013 year was the first complete year scheduled using ORSA. The intervening 2011-2012 academic year was a year of transition and was therefore omitted.

During both study years, the ED had six required resident shifts: 7:00am-4:00pm, 9:00am-6:00pm, 4:00pm-1:00am, 5:00pm-2:00am, 8:00pm-5:00am, and 11:00pm-8:00am. Two additional optionally-filled shifts, one from 10:00am-7:00pm and another from 12:00pm-9:00pm, were filled as frequently as possible.

Residency programs that staffed the ED included pediatrics, combined medicine and pediatrics, emergency medicine, and family medicine. Educational requirements outside of the ED differed for each group; details are described in Appendix A. To be feasible, schedules had to allow residents to attend their outside requirements and still abide by ACGME rules. These rules dictated that residents have a minimum of four 24-hour periods off per month, a maximum of 80 hours worked per week, a minimum of 10 hours between separate shifts or responsibilities, and a maximum of six consecutive night shifts.

To assess schedule quality, four specific measures were evaluated: total shift disparity, night shift disparity, occurrence of shifts immediately following outside clinic responsibilities ("post-clinic shifts"), and occurrence of challenging shift transitions ("bad sleep patterns," BSPs). Total shift disparity and night shift disparity refer to variance in numbers of shifts among residents in any given month. Post-clinic shifts were chosen as a negative quality metric because of the difficulty of preceding a shift with outside requirements. Bad sleep patterns were defined as consecutive shift assignments that yield a negative sleep schedule for residents, and were determined by informally surveying senior residents on challenging shift transitions. These BSPs are listed in Table 1.

Data collected included the monthly numbers of residents working in the ED, total shifts per resident, night shifts per resident, post-clinic shifts, and BSPs. Department of Pediatrics chief residents were informally surveyed on the amount of time necessary to create a schedule, both by hand and utilizing ORSA.

Statistical analysis was completed using Minitab® 16 (Minitab Inc., State College, PA, USA).

This quality improvement project was exempt from IRB oversight.

RESULTS

In the 2010-2011 year, each month's schedule required 12 to 16 hours to build manually, plus 10 to 12 additional hours of later corrections. In the 2012-2013 year, the schedule took between two to three hours of file-building, plus two to three hours of modification with the engineering team. There was little-to-no error correction time needed. In sum, the total time to build a monthly schedule was between 22 and 28 hours by hand, and four to six hours utilizing ORSA.

A mean of 13.44 (SD = 2.81, SEM = 0.57) residents worked per month in the ED, normalized per month, such that a resident who was working in the ED for 15 days in a 30-day month was counted as 0.5 residents.

Bad sleep patterns, post-clinic shifts, and measures of shift disparity were calculated for each month in the 2010-2011 and 2012-2013 academic years, as well as averaged within each year. Student's t-tests compared the year-averaged data between the study years, and paired t-tests compared the month-averaged data (Table 2).

The number of BSPs decreased significantly from the 2010-2011 to 2012-2013 academic year, from a mean of 0.63 to 0.09 BSPs per resident per month (mean change -0.54, $p < 0.001$, 95%

CI: (-0.29, -0.79)). Similarly, the number of post-clinic shifts decreased significantly with the mean dropping from 0.54 to 0.18 post-clinic shifts per resident per month (mean change -0.36, p < 0.001, 95% CI: (-0.16, -0.57)).

While there was no significant difference in total shift disparity between years (mean change -0.02, p = 0.33, 95% CI (-0.04, 0.00)), there was statistically significant reduction in night shift disparity, from 0.09 to 0.04 (mean change -0.05, p < 0.001, 95% CI: (-0.03, -0.07)).

In month-matched paired t-tests, BSPs, post-clinic shifts, and night shift variability continued to be significantly reduced between study years, with mean changes of -0.54, -0.36, and -0.05, respectively (all p < 0.001). Total shift disparity was not significantly different between the month-matched data (mean change = -0.02, p = 0.49).

Results were assessed for dependence on the number of residents working in the ED per month, a number which fluctuated across months. Pearson correlation coefficients were calculated for the linear dependence of BSPs, post-clinic shifts, and shift disparity on the number of residents working in the ED (Table 3). Coefficients were calculated for both academic years individually and for the two years grouped together. Nine out of 12 interactions had coefficients of less than 0.20, another two out of 12 had coefficients less than 0.50, and the final coefficient was 0.53.

DISCUSSION

The advent of the scheduling tool significantly improved several measures of schedule quality. Bad sleep patterns, post-clinic shifts, and night shift disparity all significantly decreased from

2010-2011 to 2012-2013. The change in total shift disparity was not significant, but this is not surprising; the easiest quality measure to check by hand is a count of each resident's shifts per month, and this is where schedulers often invest time in improving handmade schedules.

These improvements in schedule quality came while *decreasing* the time required for production, as ORSA reduced schedule creation time by over 20 hours per month. This was partly attributable to the accuracy of automated schedules. While handmade schedules typically required hours of later corrections, ORSA schedules required little to none.

Pearson correlation coefficients revealed that these significant changes in schedule quality were not due to the monthly resident complement. The coefficients for the interaction of the metrics and the number of residents per month are remarkably low, explaining less than 20% of most of the measured outcomes. In short, improved outcomes cannot be attributed to increased resident numbers.

The benefits of using computer assistance in resident scheduling are numerous. Automation allows adaption to each month's different resident complement and optimization priorities. Such flexibility leads to increased efficiency, as the scheduler is not forced to start from scratch when these variables change. Currently, this flexibility is relatively unique in the world of scheduling tools. Most tools are focused on nursing, a field with very different scheduling constraints compared to residency. Additionally, most of what is currently available optimizes a certain parameter of a schedule, such as shift preference or cost.[10-12] However, an ideal scheduling tool incorporates ad-hoc adjustments, prioritizing different metrics according to the needs of that month. By not optimizing one pre-determined trait, ORSA allows a scheduler to choose what parameter they want to optimize each month.

Another benefit to automation is the reduced time required to complete a schedule. Using ORSA freed roughly 20 hours per month of the scheduler's time, allowing him or her to move on to other duties. Furthermore, little to no correction was needed of completed schedules later in the month.

Improved schedule quality addresses bad sleep patterns that contribute to resident fatigue, a common plague of residency programs. Tired residents display cognitive declines in a variety of areas, are more likely to make mistakes,[1-3,7] and are more likely to experience burnout. Fatigue also contributes to the increased incidence of motor vehicle accidents among medical residents.[6,8] Better scheduling cuts down on factors leading to resident fatigue and therefore danger.

Since resident satisfaction, fine-motor skills, or patient care were not directly assessed, the scope of this paper is limited to the described schedule quality metrics; we cannot definitively state that automated scheduling improves patient care or resident morale. These topics may be a focus of future research. However, it follows logically that a schedule that considers the human factors of shift work may yield improvement in those categories. Another limitation is our statistical power, as our sample size was limited to two academic years. Finally, bad sleep patterns were defined based on experience and resident feedback; there is no evidence specifically associating these shift transitions with poor patient care or educational outcomes.

CONCLUSION

In conclusion, automated shift scheduling tools like ORSA improve the current manual scheduling process. Automated schedules are made faster and are of higher quality than schedules made by hand, and they are able to efficiently incorporate changing scheduler preferences from month to month. It is our hope that improving schedule quality in this way can improve patient safety, resident education, and morale. Residency programs should strongly consider adopting such tools to meet the challenging and ever-changing demands of resident shift scheduling.

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TABLES

Shift Combinations Yielding Bad Sleep Patterns
1. Day 1: 12 PM – 9 PM, Day 2: 7 AM – 4 PM
2. Day 1: 4 PM – 1 AM, Day 2: 12 PM – 9 PM
3. Day 1: 5 PM – 2 AM, Day 2: 12 PM – 9 PM
4. Day 1: 8 PM – 5 AM, Day 2: 4 PM – 1 AM
5. Day 1: 8 PM – 5 AM, Day 2: 5 PM – 2 AM
6. Day 1: 8 PM – 5 AM, Day 3: 7 AM – 4 PM
7. Day 1: 11 PM – 8 AM, Day 3: 7 AM – 4 PM
8. Day 1: 11 PM – 8 AM, Day 3: 9 AM – 6 PM

Table 1: The eight bad sleep patterns (BSPs) are defined.

	Academic Year 2010-2011				**Academic Year 2012-2013**				**Difference**			
	Total	*Mean per resident per mo.*	*SD*	*SEM*	*Total*	*Mean per resident per mo.*	*SD*	*SEM*	*Mean Δ per resident per mo.*	*% change*	*Unpaired p-value*	*Paired p-value*
Bad Sleep Patterns	83	0.63	0.28	0.08	14	0.09	0.31	0.09	-0.54	-85.7%	< 0.01	< 0.01
Shifts After Clinics	72	0.54	0.26	0.08	32	0.18	0.22	0.06	-0.36	-66.7%	< 0.01	< 0.01
Total Shift Variability *SD in Shifts / Day*	–	0.08	0.02	0.01	–	0.06	0.03	0.01	-0.02	-25.0%	0.49	0.33
Night Shift Variability *SD in Night Shifts / Day*	–	0.09	0.03	0.01	–	0.04	0.02	0.00	-0.05	-44.4%	< 0.01	< 0.01

Table 2: Quality metrics are normalized for monthly resident compliment, then averaged both per-month and per-year.

	2010-2011	2012-2013	Grouped
Bad Sleep Patterns	0.10	0.17	0.48
Shifts After Clinics	0.01	0.00	0.16
Total Shift Disparity *(SD in Shifts / Day)*	0.43	0.00	0.09
Night Shift Disparity *(SD in Night Shifts / Day)*	0.20	0.05	0.53

Table 3: Pearson's correlation coefficients assess the dependence of quality metrics on resident compliment.

Residency Program	Outside Activity	Day of Week	Time
Pediatrics	Community clinic	Varied	1:00 PM - 5:00PM or 9:00 AM - 12:00PM
Emergency Medicine	Program-specific educational activity	Wednesday	10:00 AM - 2:00 PM
Family Medicine, HO-1	Community clinic	Wednesday	9:00 AM - 5:00 PM
Family Medicine, HO-3	Community clinic	Monday and Wednesday	9:00 AM - 5:00 PM