Resident Scheduling for Pediatric Night Shifts Using OpenSolver

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Background

- Throughout the year, medical residents rotate on different services to develop their clinical abilities. One common rotation is the Night Team, in which residents cover the inpatient units overnight.
- A Chief Resident is tasked with determining which residents work each night. This task is done by hand, time-consuming, and error-prone. We aim to automate this process to enable faster, improved scheduling.
- We also include Clinic Scheduling in the model to help ease the process of the two interrelated scheduling blocks.

Methods

- We formulate the problem as an integer programming model.
- In collaboration with the Chief Resident, we developed metrics to evaluate schedule quality.
- We implemented the model in Microsoft Excel using the OpenSolver add-in.
- Each month, the Chief Resident provides the inputs for the schedule. These inputs list the residents, their respective start and end dates, and requested days off.
- Using Excel, we solve the model and the resulting schedule is provided to the Chief Resident for review.

Model

Sets

R	set of residents	D	set of dates
R_P	subset group of Pediatrics residents	W_1	Weeks relative to Peds/MP Interns
R_M	subset group of Medicine-Pediatrics residents	W_2	Weeks relative to Seniors/EM Interns
R_E	subset group of Emergency Medicine residents		
R_I	subset group of Interns (first-year residents)		
R_S	subset group of Seniors (second- to fourth-year residents)		

Parameters

a_i	Required number of interns on the team each night
A_s	Required number of seniors on the team each night
M_{nt}	Maximum number of permissible consecutive days working on the team
m_{nt}	Minimum number of permissible consecutive days working on the team
ω_1	Weight of assigning 2-night sequence
ω_2	Weight of assigning 6-night sequence

Decision Variables

x_{rad}	1 if resident r is assigned activity a on date d	$\forall r \in R, a \in A, d \in D$
y_{rw}	1 if resident r is assigned to conference on week w	$\forall r \in R, w \in W$
z_{rd}	1 if resident r is assigned to clinic on date d	$\forall r \in R, w \in W$
f_{rd}	1 if resident r works exactly 2 night shifts over 3-day stretch beginning date d	$\forall r \in R, d \in D$
m_{rd}	1 if resident r works exactly 6 night shifts over 6-day stretch beginning date d	$\forall r \in R, d \in D$

Model

Objective Function

To minimize the number of times residents are assigned 2-day or 6-day Night Shift sequences.

$$\min \sum_{r \in R} \sum_{d \in D} \omega_1 f_{rd} + \omega_2 m_{rd}$$

Rules

Activity Limit: Each shift sequence must contain at least 2 nights.

$$\sum_{a \in A} x_{rd} = 1, \ \forall r \in R, d \in D$$

Coverage Requirements: The night team requires: (1) zero or two interns every day, and (2) two, three or four seniors every day.

$$\sum_{r \in I} x_{r(nt)d} = a_i, \ \forall d \in D$$
$$\sum_{r \in S} x_{r(nt)d} = a_s, \ \forall d \in D$$

Clinic Requirements: The residents must also be scheduled for clinics, separate from the obligation to the Nights team. Each resident requires 1 clinic day (1) when their clinic is available. It must be on a day before they begin a Night sequence (2).

$$\sum_{d \in C_r} z_{rd} = 1, \ \forall r \in R$$
$$z_{rd} \leq x_{r(nt)(d+1)}, \forall r \in R, d \in D$$

Minimum Work Sequences: Every resident's Nights sequence must be at least 2 consecutive nights.

$$x_{r(nt)0} \leq x_{r(nt)(1)}, \forall r \in R$$
$$x_{r(nt)d} \leq x_{r(nt)(d-1)} + x_{r(nt)(d+1)}, \forall r \in R, d \in (1, \dots, numDates - 2)$$
$$x_{r(nt)(numDates-1)} \leq x_{r(nt)(numDates-2)}, \forall r \in R$$

Maximum Work Sequences: Every resident's Nights sequence must not exceed 6 consecutive nights.

$$\sum_{d=d'}^{d'+M^{nt}} x_{r(nt)d} \leq M^{nt}, \ \forall r \in R, d' \in (0, \dots, numDates - M^{nt} - 1)$$
$$\sum_{d=d'}^{d'+M^{do}} x_{r(nt)d} \leq M^{do}, \ \forall r \in R, d' \in (0, \dots, numDates - M^{do} - 1)$$

Emergency Medicine Conferences: Residents must attend at least one of their conferences during the two-week rotation. Conference is on a Tuesday and Wednesday.

$$\sum_{w \in W} y_{rw} \geq 1, \ \forall r \in E$$
$$y_{rw} \leq w_{r(do)(Tues_w)}, \forall r \in E, w \in W_i$$
$$y_{rw} \leq w_{r(do)(Wed_w)}, \forall r \in E, w \in W_i$$

Metrics

Preferred Durations of Work Sequences: Ideally, residents should work between 3 and 5 night shifts in a row.

$$f_{r0} + m^{nt} - 1 \geq x_{r(nt)0} + x_{r(nt)1} - x_{r(nt)2}, \forall r \in R$$
$$f_{rd} + m^{nt} - 1 \geq -x_{r(nt)(d-1)} + x_{r(nt)d} + x_{r(nt)(d+1)} - x_{r(nt)(d+2)},$$
$$\forall r \in R, d \in (0, \dots, numDates - m^{nt} - 1)$$
$$f_{r(numDates-2)} + m^{nt} - 1$$
$$\geq -x_{r(nt)(numDates-3)} + x_{r(nt)(numDates-2)} + x_{r(nt)(numDates-1)},$$
$$\forall r \in R$$
$$m_{rd} + M^{nt} - 1 \geq \sum_{d'=d}^{d+M^{nt}-1} x_{r(nt)d'},$$
$$\forall r \in R, d \in (0, \dots, numDates - M^{nt} - 1)$$

Preferred Shift Equity: Ideally, residents should have the same amount of shifts per block.

$$\delta_r \geq \bar{x} - \sum_{d \in D} x_{r(nt)d}, \forall r \in R$$
$$\delta_r \geq \sum_{d \in D} x_{r(nt)d} - \bar{x}, \forall r \in R$$

Solution Approach

- We formulated a linear programming model and implemented in a Microsoft Excel workbook, using the OpenSolver add-in.

Sample Inputs

	Name	Program	Clinic	Start Date	End Date	LB Shifts	UB Shifts
Intern 1	Cartwright	PEDS	Briarwood	27-Apr	10-May	8	12
Intern 2	Rompca	PEDS	Northville	27-Apr	10-May	8	12
Intern 3	Jarrett	PEDS	Canton	12-May	25-May	8	12
Intern 4	Sliwicki	PEDS	EAA	12-May	25-May	8	12

	27-Apr	28-Apr	29-Apr	30-Apr	1-May	2-May	3-May
	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday
Min Interns	2	2	2	0	0	2	2
Max Interns	2	2	2	0	0	2	2
Min Seniors	0	0	0	0	3	2	2
Max Seniors	0	0	0	0	4	3	3

Min Number Consecutive Shifts	2
Max Number Consecutive Shifts	6
Daily Resident Activity Limit	1
First Day in Planning Horizon	27-Apr
Planning Horizon Duration	35
First Valid Conference Day	6-Mar
2-day Work Sequence Weight	1
6-day Work Sequence Weight	50

Sample Outputs

Activity Report	27-Apr	28-Apr	29-Apr	30-Apr	1-May	2-May	3-May
	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday
Min Interns	Night Team	Night Team	Night Team	*Day Off*	*Day Off*	Night Team	Night Team
Max Interns	Night Team	Night Team	Night Team	*Day Off*	Clinic Day	Night Team	Night Team
Min Seniors	*Day Off*	*Day Off*	*Day Off*	*Day Off*	*Day Off*	*Day Off*	*Day Off*
Max Seniors	*Day Off*	*Day Off*	*Day Off*	*Day Off*	*Day Off*	*Day Off*	*Day Off*

Impact

- By using linear programming to develop the schedule, assignment equity and request satisfaction improved.
- Moreover, the tool accommodates manipulation to better fit the Chief Resident's ideal schedule.
- As the Chief Resident gained experience with the tool, more schedule metrics were identified to further improve quality.
- Our program generates full schedules rapidly (solve time < 15 s).
- We derived high impact results from mathematically simple, straight-forward modeling with an undergraduate-led project team.
- Based on mutual satisfaction from the project we fostered long-term collaboration with the medical school.

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