HEALTHCARE SYSTEMS PROCESS IMPROVEMENT CONFERENCE 2016

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LEADING HEALTHCARE IMPROVEMENT

Scheduling Healthcare Providers

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Presentation outline

Motivation

C.S. Mott Emergency Room shift scheduling

Residency rotation scheduling

Conclusions and potential opportunities

Scheduling needs in healthcare

Physician scheduling

Nurse scheduling

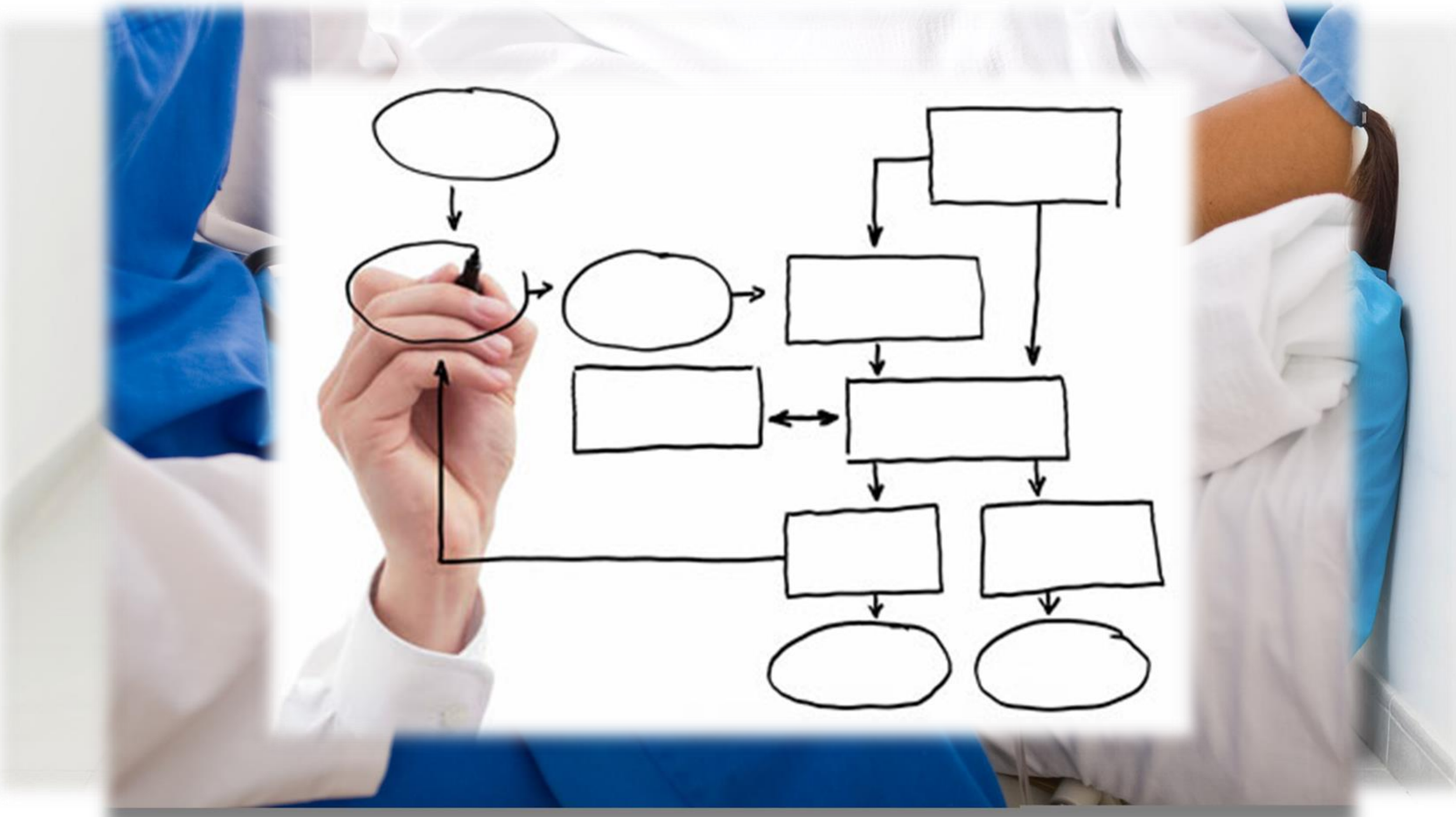
Operating room scheduling

Appointment scheduling

Many more…

Scheduling affects…

…and satisfaction



Traditional approach

Schedules hand-built by program director, chief resident(s), or administrator

Benefits

1) Intimate problem knowledge
2) Administrative consolidation
3) Streamlined approval process

Drawbacks

1) Time-consuming process
2) High cognitive demand
3) Limited consideration of tradeoffs

Medical training at UMHS

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C.S. Mott Pediatric Emergency Room

Level I Pediatric Trauma Center

About 25,000 visits per year

Staffed by 5 residency programs

- Pediatrics
- Medicine-Pediatrics
- Family Medicine
- Emergency Medicine
- Psychology

Resident scheduling challenges

Resource-intensive process

- Chief resident spends 20 – 25 hours per month
- Numerous revisions

Complicated requirements

- Legal, regulatory, and administrative rules
- Resident education
- Service coverage

Decision variables

Whether to assign resident **r** to shift **s** on day **d**

$$x_{rsd} \in \{0, 1\}, \qquad \forall\, r \in R, s \in S, d \in D$$

Shift coverage

Must provide sufficient shift coverage for every day and shift

$$\sum_{r \in R} x_{rsd} = 1, \qquad \forall\, d \in D, s \in S \setminus \{\text{flex}, \text{EOM}, \text{EMSr}\}$$

$$0 \leq \sum_{r \in R} x_{rsd} \leq 1, \qquad \forall\, d \in D, s \in \{\text{flex}, \text{EOM}\}$$

$$\sum_{r \in R} x_{rsd} = 0, \qquad \forall\, d \in D, s \in \{\text{EMSr}\}$$

Total shifts

Must provide adequate educational experience for every resident

$$\mathrm{LBShifts}_r \leq \sum_{s \in S} \sum_{d \in D} x_{rsd} \leq \mathrm{UBShifts}_r, \quad \forall r \in R$$

$$\mathrm{LBNites}_r \leq \sum_{s \in S} \sum_{d \in D} x_{rsd} \leq \mathrm{UBNites}_r, \quad \forall r \in R$$

External requirements

Cannot create work assignments that conflict with outside commitments

$$x_{rsd} = 0, \quad \forall\, r \in R, d \in D, s \in \{\text{conferences}, \text{clinics}, \text{vacations}, \text{etc.}\}$$

Pediatric paired shifts

Ensure that at least 1 of 2 shifts in a pair is covered by a Pediatric resident each day

$$\sum_{r \in \{PED\}} \sum_{s \in P} x_{rsd} \geq 1,$$

$$\forall\, d \in D, P = \{\{7a,9a\}, \{4p,5p\}, \{8p,11p\}\}$$

Senior-only shifts

Certain shifts must be covered by senior-level residents

$$\sum_{r \in \{\text{interns}\}} \sum_{d \in D} x_{rsd} = 0, \qquad \forall\, s \in \{7a, 11p\}$$

Work-rest rules

Residents must get at least 10 hours off-duty between ending one shift and beginning another

$$x_{rsd} + \sum_{\substack{(s',d') \in \\ \{\text{within 10 hrs of } (s,d)\}}} x_{rs'd'} \leq 1,$$

$$\forall\, r \in R, s \in S, d \in D$$

Multi-criteria objective

Multi-criteria schedule

- Total shift equity (TSE)
- Night shift equity (NSE)
- Bad sleep patterns (BSP)
- Post-continuity clinic shifts (PCC)
- ⋮

Preferences?
Weights?
Trade-off?

Multi-objective Mathematical Programming

Multi-criteria objective

Optimization problem

$$\begin{aligned}&\textbf{Min}\ \boldsymbol{w_1}(TSE) + \boldsymbol{w_2}(NSE) + \boldsymbol{w_3}(BSP) + \boldsymbol{w_4}(PCC)\\ &\textbf{s.t.}\qquad \text{"rules/requirements"}\\ &\qquad\qquad x_{rsd} \in \{0,1\}\end{aligned}$$

Quantifying preferences (w_i) is difficult

- Subjective weights
- Alternative measures
- Non-linearity

Multi-criteria objective

Feasibility ~~Optimization~~ problem

$$
\begin{aligned}
&\textbf{Min}\ \sout{w_1(TSE) + w_2(NSE) + w_3(BSP) + w_4(PCC)}\\
&\textbf{s.t.}\qquad \text{"rules/requirements"}\\
&\qquad\qquad x_{rsd} \in \{0,1\}\\
&\qquad\qquad lb_{TSE} \le (TSE) \le ub_{TSE}\\
&\qquad\qquad lb_{NSE} \le (NSE) \le ub_{NSE}\\
&\qquad\qquad lb_{BSP} \le (BSP) \le ub_{BSP}\\
&\qquad\qquad lb_{PCC} \le (PCC) \le ub_{PCC}
\end{aligned}
$$

Benefits of a feasibility problem

- Flexibility
- Speed: < 2 seconds per iteration

  Given: 20 residents / 7 shifts daily / 35 days

Iterative improvement

Resident Name	Number of Shifts	Number of Night Shifts	Number of Post-CC Shifts	Number of Bad Sleep Patterns
Smith	8 (7,9)	2 (2,3)	0 (0,1)	0 (0,0)
Sanchez	8 (7,10)	2 (2,3)	0 (0,1)	0 (0,0)
Chen	8 (7,9)	2 (2,3)	1 (0,1)	0 (0,0)
Shah	14 (13,15)	4 (3,5)	1 (0,1)	0 (0,0)
⋮	⋮	⋮	⋮	⋮

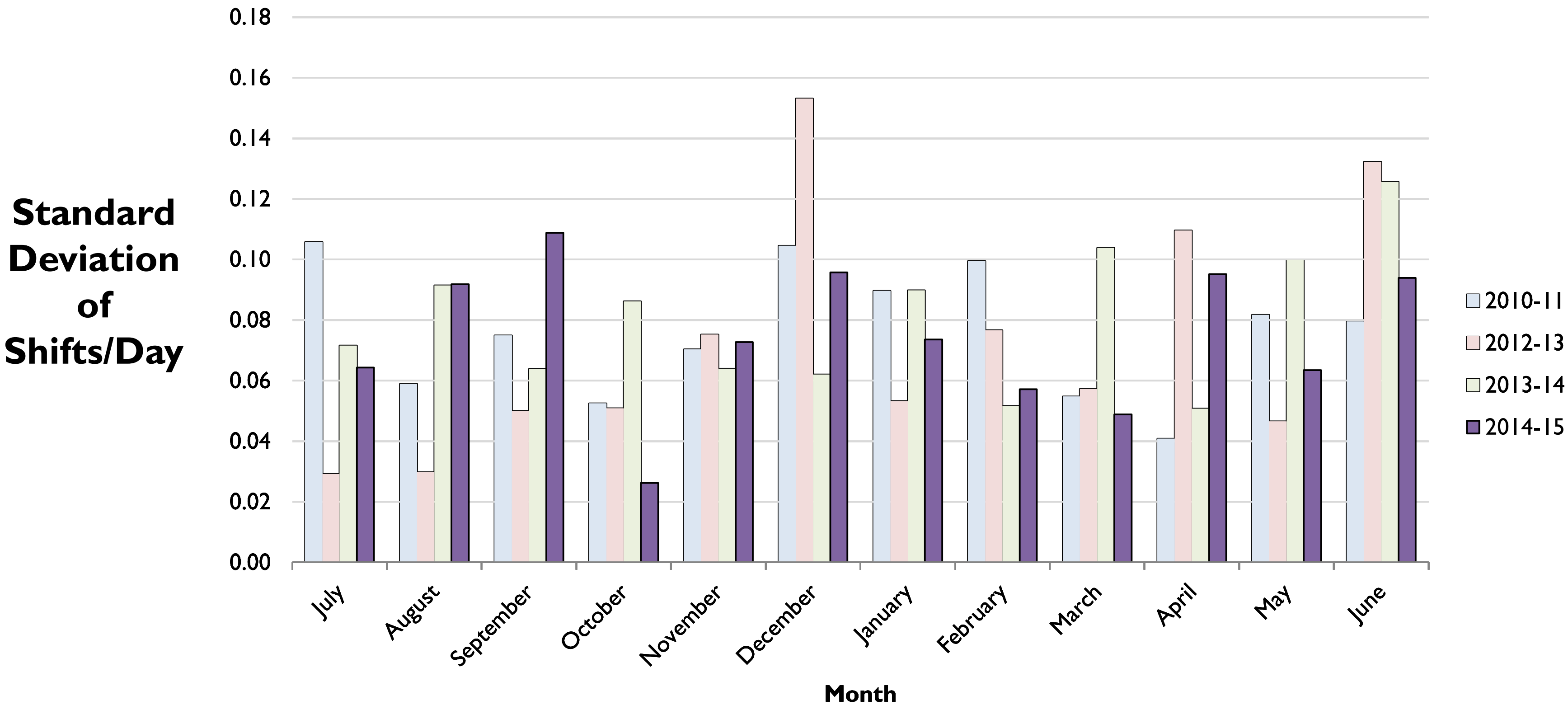
Implementation results

Reduced time to create schedules

20 hours per month	→	1 hour per month

Statistically significant improvement in 3 of 4 major metrics

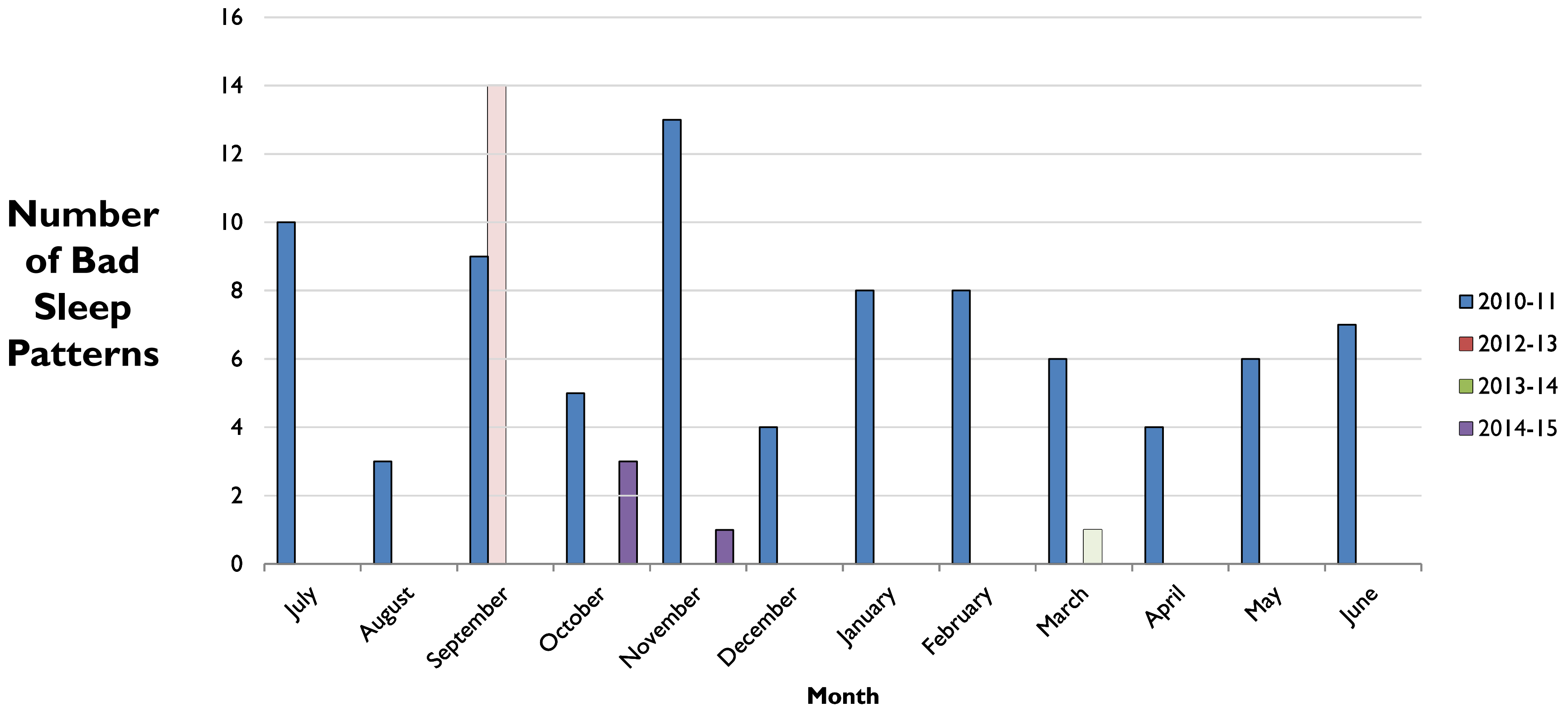
Total shift equity



2010-11: 0.0761 ± 0.0214 2013-14: 0.0801 ± 0.0231

2012-13: 0.0665 ± 0.0367 2014-15: 0.0743 ± 0.0238

Bad sleep patterns



2010-11: 6.9167 ± 2.8749

2012-13: 1.1667 ± 4.0415

2013-14: 0.0833 ± 0.2887

2014-15: 0.3333 ± 0.8876

Implementation summary

Months with poor metrics tend to have:

- Fewer residents overall
- Fewer senior residents
- Fewer Pediatrics residents

Simulation study

Percentage Feasible (of 2,000 Iterations)

Total Residents	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
20	5.4%	33.0%	66.8%	84.8%	92.6%	95.9%	95.2%	96.4%	95.7%	96.1%
19	6.2%	32.4%	60.7%	79.7%	89.5%	93.1%	94.0%	93.5%	94.2%	94.3%
18	4.1%	25.8%	55.2%	76.2%	87.6%	88.9%	91.4%	91.1%	92.2%	92.6%
17	3.8%	25.0%	48.8%	71.4%	81.9%	86.4%	89.3%	87.8%	86.9%	89.1%
16	2.2%	20.0%	45.6%	65.5%	77.0%	81.0%	80.0%	83.3%	82.4%	82.9%
15	2.1%	16.6%	35.2%	55.7%	69.2%	75.4%	74.0%	76.2%	76.7%	75.7%
14	1.2%	11.4%	29.2%	47.9%	58.9%	63.2%	66.9%	67.9%	67.3%	67.8%
13	0.7%	7.4%	22.9%	36.4%	48.5%	55.5%	55.7%	54.4%	56.4%	56.2%
12	0.6%	6.0%	16.3%	27.2%	34.2%	41.0%	41.8%	40.8%	41.7%	42.9%
11	0.3%	3.4%	8.8%	15.5%	22.4%	27.5%	27.5%	25.9%	28.1%	28.1%

Pr(Senior Standing)

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Rotation scheduling

Assigning residents to services over the course of the academic year

Must simultaneously satisfy **service coverage needs** and **academic requirements**

Typically month-long rotations

Pediatric Residency Program

Training in inpatient and ambulatory settings

Integration with combined programs

Service pair:
an ordered couplet of services that may be worked during the same month

Service Pair p	
1st Half Service	2nd Half Service
Hard Rotation? (1 = Yes, 0 = No)	

Department of Surgery

Residencies and fellowships in

- General
- Vascular
- Anesthesiology
- Plastic
- Thoracic
- Many more…

Service and education integration with numerous other programs and institutions

Decision variables

Whether to assign resident **r** to service **s** (or pair **p**) on month **m**:

Pediatric Residency Program

$$x_{rpm} \in \{0, 1\},$$

$$\forall\, r \in R, p \in P, m \in M$$

Department of Surgery

$$x_{rsm} \in \{0, 1\},$$

$$\forall\, r \in R, s \in S, m \in M$$

Monthly rotation assignment

Each resident is assigned one service (pair) per month

Pediatric Residency Program

$$\sum_{p \in P} x_{rpm} = 1,$$

$$\forall\, r \in R, m \in M$$

Department of Surgery

$$\sum_{s \in S} x_{rsm} = 1,$$

$$\forall\, r \in R, m \in M$$

Service coverage

Each service must have between a minimum **L** and maximum **U** number of residents (fitting a certain category **c**) at any time

Pediatric Residency Program

$$L_{sm} \leq \sum_{p \in P_{sh}} x_{rpm} \leq U_{sm},$$

$$\forall\, s \in S, m \in M, h \in \{1, 2\}$$

Department of Surgery

$$L_{csm} \leq \sum_{r \in R} a_{rc} x_{rsm} \leq U_{csm},$$

$$\forall\, c \in C, s \in S, m \in M$$

Resident education

Each resident must work between a minimum **λ** and maximum **μ** number of months on each service throughout the year

Pediatric Residency Program

$$\lambda_{rs} \leq \sum_{p \in P} \sum_{m \in M} a_{ps} x_{rpm} \leq \mu_{rs},$$

$$\forall\, r \in R, s \in S$$

Department of Surgery

$$\lambda_{rs} \leq \sum_{m \in M} x_{rsm} \leq \mu_{rs},$$

$$\forall\, r \in R, s \in S$$

PEDIATRIC RESIDENCY PROGRAM-SPECIFIC CONSTRAINTS

Triple-hard sequences

Residents may work a limited number of sequences of 3 hard service pairs $\mathbf{h_p}$ in a row

$$\sum_{p \in P} h_p x_{rpm} + h_p x_{rp(m+1)} + h_p x_{rp(m+2)} \leq y_{rm} + 2, \quad \forall\, r \in R, m \in \{1, \dots, |M| - 2\}$$

$$\sum_{m \in M} y_{rm} \leq \mathcal{H}_r, \quad \forall\, r \in R$$

DEPARTMENT OF SURGERY-SPECIFIC CONSTRAINTS

Extended rotations

Residents assigned to services in extended rotation rule **e** must be assigned for consecutive months equal to the specified duration $\mathbf{d^e}$

$$x_{rs[d^e \times (i-1)]} = x_{rs\{[d^e \times (i-1)]+j\}},$$

$$\forall\, e \in E, r \in R^e, s \in S^e,$$

$$i \in \{1, \dots, |M|/d^e\},$$

$$j \in \{1, \dots, d^e - 1\}$$

Service sequencing

Residents included in sequencing rule **q** must be assigned to certain services prior to being assigned to a particular service **s_q'**

$$\mathcal{L}^q \le \left[\sum_{s \in S^q} \sum_{m \in M^q} x_{rsm}\right] - \sum_{\in \mathcal{R}^n} x_{rs'_q m'_q}$$

$$\forall\, q \in Q, r \in R^q$$

Service spacing

Residents must not be assigned to a certain service more than once in a certain timeframe

$$\sum_{m \in M^a} x_{rsm} \leq 1, \qquad \forall\, a \in A, r \in R^a, s \in S^a$$

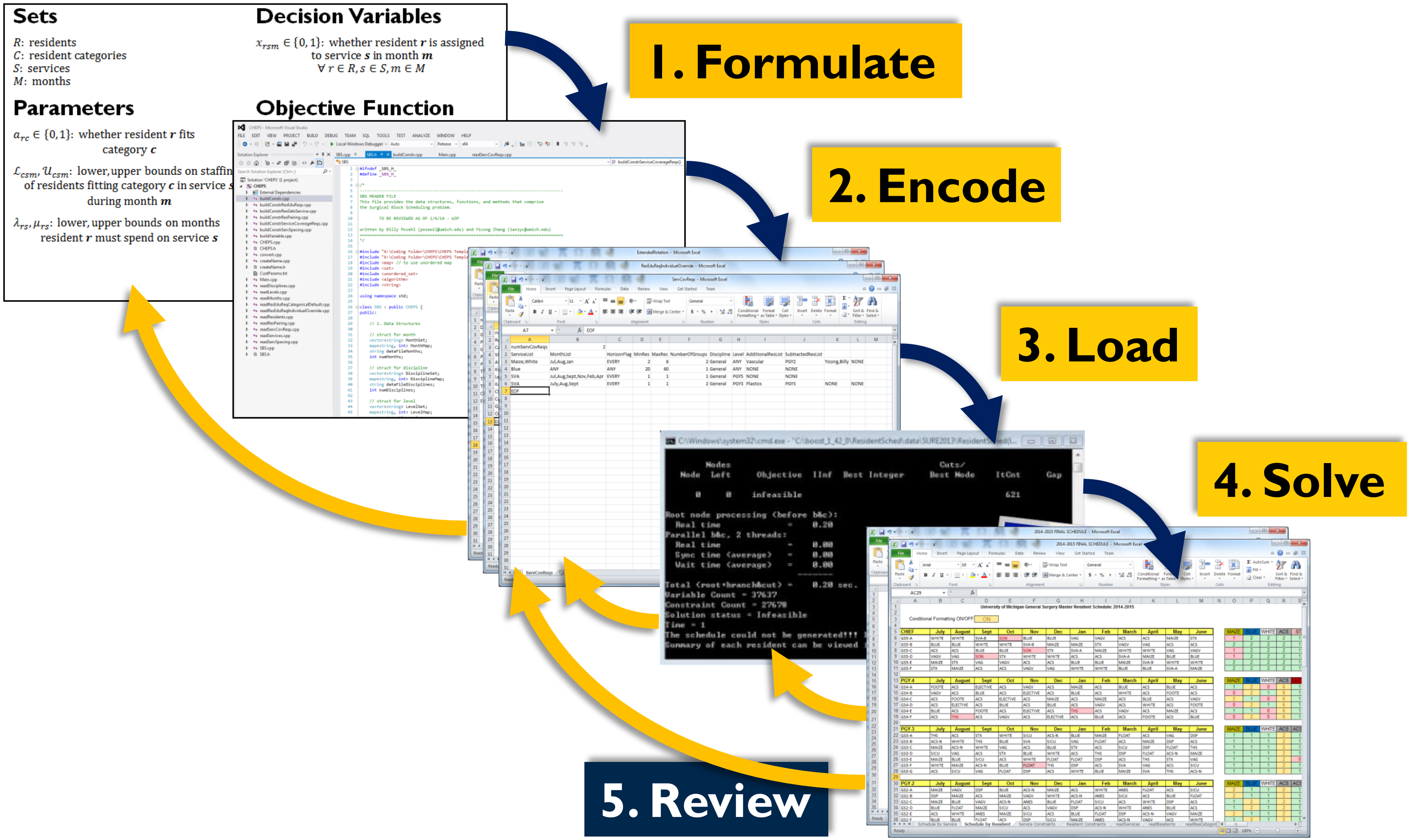
Resident pairing

Assigning residents in resident pair rule **n** from group $\mathbf{R^n}$ to services $\mathbf{S^n}$ requires also assigning residents from group $\boldsymbol{\mathcal{R}}^{\mathbf{n}}$ to services $\boldsymbol{\mathcal{S}}^{\mathbf{n}}$

$$\ell_{sm}^{n} \leq \sum_{r \in R^n} \sum_{s \in S^n} x_{rsm} - \sum_{\mathscr{r} \in \mathcal{R}^n} \sum_{\mathscr{s} \in \mathcal{S}^n} x_{\mathscr{r}\mathscr{s}m} \leq \mathcal{u}_{sm}^{n}$$

$$\forall\, n \in N, s \in S^n, m \in M^n$$

Implementation process



Implementation comparison

Pediatric Residency Program

99 residents | **4** programs | **14** services

Two-phase schedule creation
- Senior phase
- Intern phase

≤3 minutes/iteration

Satisfied **238/242 (98.3%)** of requests made for Pediatric Residency Program

Department of Surgery

118 residents | **10** programs | **62** services

Multi-phase schedule creation
- Program lock-ins
- Individual lock-ins

≤5 minutes/iteration

Facilitated customized program tracking for **12 residents**

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Emergency Department shift scheduling

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Conclusions

Significantly reduced time and improved metrics for ED shift schedules

Lingering scheduling challenges may derive from the rotation schedule

Significantly improved satisfaction of time preferences for rotation schedules

Ongoing work

Generalize models into universal formulation

Extend model to address other residency programs' needs

Apply algorithm to identify maximally feasible sets of requests

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Questions [?] and comments [!]

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