Improving Chemotherapy Scheduling at the BC Cancer Agency

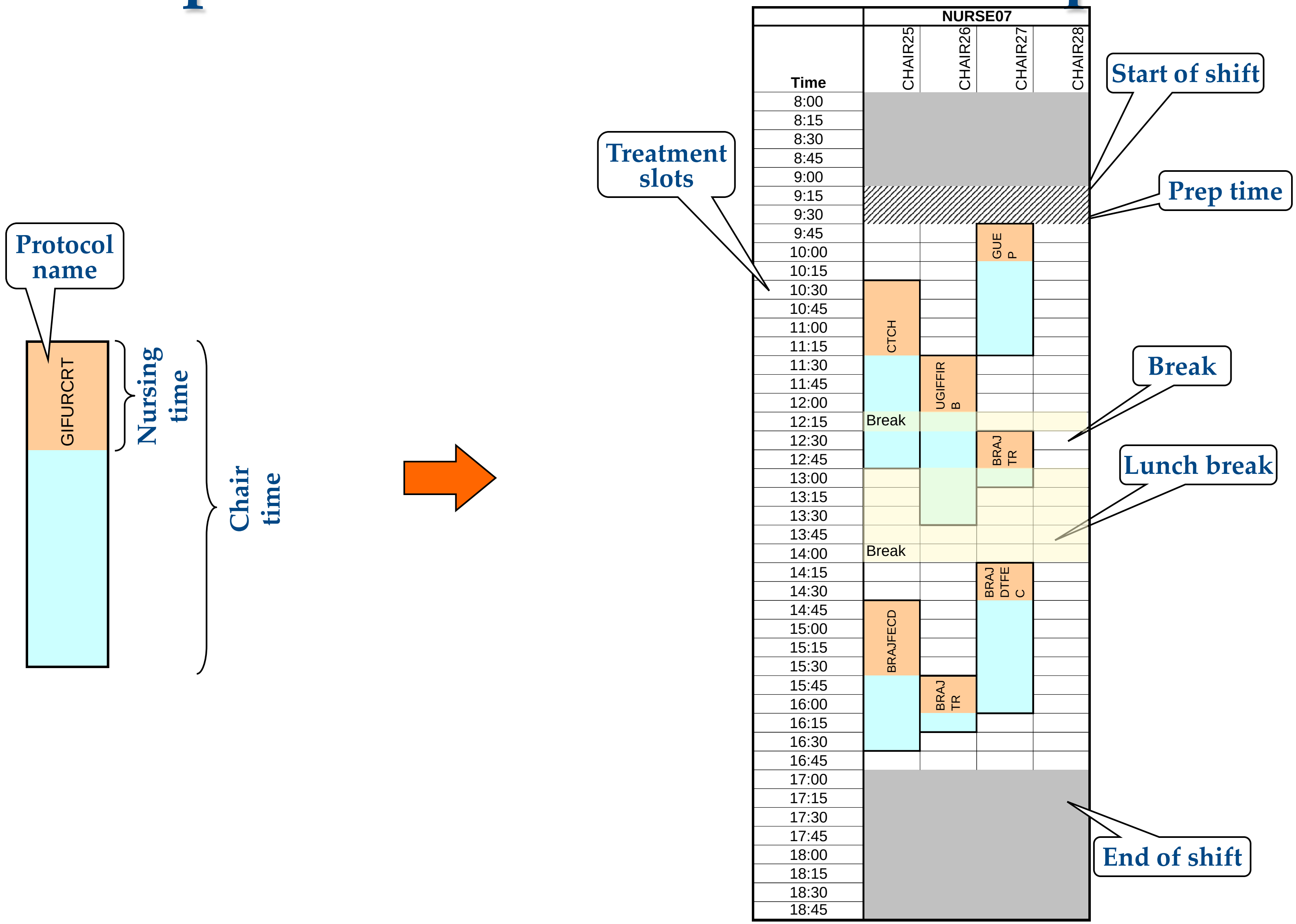
CIHR Team in

Operations Research for Improved Cancer Care

The Challenge

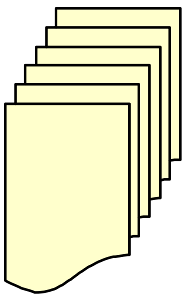
- Increasing Volumes of Chemotherapy Patients
  - New therapies
  - More cases
- Antiquated scheduling methodology
  - Burdensome on staff
    - Schedulers
    - Pharmacy
  - Inconvenient for patients
    - Most notified one day before treatment
- Goals
  - Increase time between notification and appointment
  - Simplify and automate process
  - Put changes into practice

Optimization Problem Description

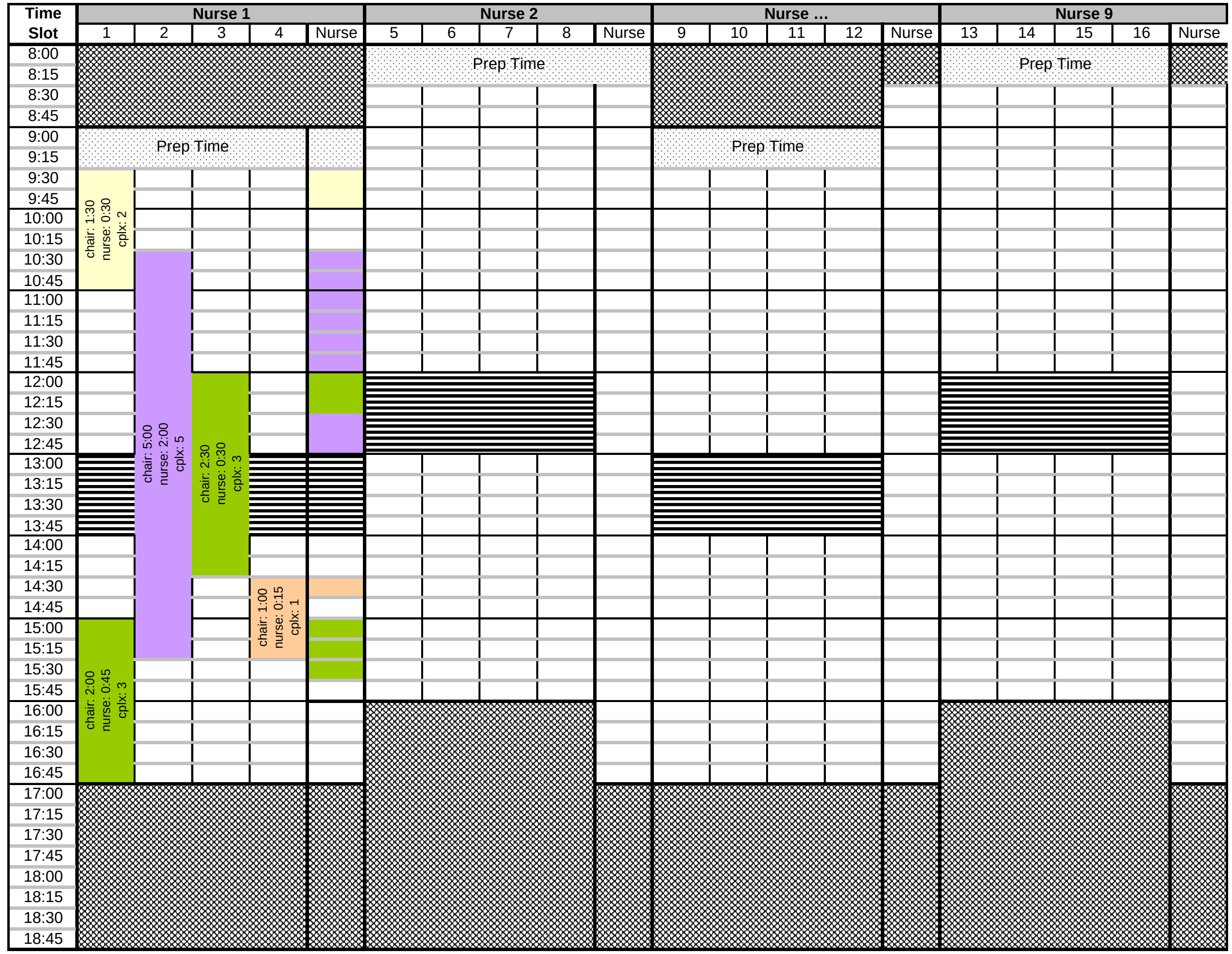


A Daily Chemotherapy Schedule

Optimization Problem Description



List of Patients



	1	2	3	4	Nurse	5	6	7	8	Nurse	9	10	11	12	Nurse	13	14	15	16	Nurse
chair:	3:30	5:00	2:30	1:00	12:00															
nurse:	1:15	2:00	0:30	0:15	4:00															
cplxity:	5	5	3	1	14															

Decision Variables

x_{ijk}^{p} $= 1$ if patient ***p*** is scheduled at treatment slot ***i*** in chair ***j*** of nurse ***k***, 0 otherwise

$$x_{ijk}^{p} \in \{0,1\}$$

Auxiliary Variables

Θ_k = 1 if nurse ***k*** has patients scheduled, 0 otherwise

Ω_{jk} = 1 if chair ***j*** of nurse ***k*** has patients scheduled, 0 otherwise

Λ = maximum nurse workload

δ_k^+ = shortfall in number of patients with respect to second part of the shift for nurse ***k***

δ_k^- = shortfall in number of patients with respect to first part of the shift for nurse ***k***

$$\Theta_k, \Omega_k \in \{0,1\}$$

$$\Lambda, \delta_k^+, \delta_k^- \geq 0$$

Parameters

ξ^p : chair time for patient $\boldsymbol{p}$

ν^p : nurse time for patient $\boldsymbol{p}$

χ^p : complexity for patient $\boldsymbol{p}$

Π_k : maximum number of patients to be assigned to nurse $\boldsymbol{k}$

Ξ_k : maximum chair time to be assigned to nurse $\boldsymbol{k}$

N_k : maximum nurse time to be assigned to nurse $\boldsymbol{k}$

X_k : maximum complexity to be assigned to nurse $\boldsymbol{k}$

Γ_k : maximum number of patients for nurse $\boldsymbol{k}$ that can start treatment simultaneously (nursing constraint)

Ψ : maximum number of patients for all nurses that can start treatment simultaneously (pharmacy constraint)

Constraints

- All patients need to be scheduled

$$\sum_{ijk} x_{ijk}^{p} = 1 \qquad \forall p$$

- At most one patient can be scheduled in a given chair at each treatment slot

$$\sum_{p} \sum_{i-\xi^{p} \leq \hat{i} \leq i} x_{\hat{i}jk}^{p} \leq 1 \qquad \forall i, j, k$$

- At most one patient receiving nursing care in any of the chairs of each nurse

$$\sum_{p} \sum_{i-\nu^{p} \leq \hat{i} \leq i} \sum_{j} x_{\hat{i}jk}^{p} \leq 1 \qquad \forall i, k$$

Constraints

- Maximum scheduled:

$$\sum_{pij} x_{ijk}^{p} \le \Pi_k \quad \forall k \quad \text{number of patients}$$

$$\sum_{pij} x_{ijk}^{p} \cdot \xi^{p} \le \Xi_k \quad \forall k \quad \text{chair time}$$

$$\sum_{pij} x_{ijk}^{p} \cdot \nu^{p} \le \mathrm{N}_k \quad \forall k \quad \text{nurse time}$$

$$\sum_{pij} x_{ijk}^{p} \cdot \chi^{p} \le \mathrm{X}_k \quad \forall k \quad \text{complexity per nurse}$$

- Maximum number of patients to start treatment simultaneously (same slot)

$$\sum_{pj} x_{ijk}^{p} \le \Gamma_k \quad \forall i,k \quad \text{per nurse}$$

$$\sum_{pjk} x_{ijk}^{p} \le \Psi \quad \forall i \quad \text{overall}$$

Constraints

- Definition of maximum nurse workload in terms of: (only one of the following active at a time)

$$\sum_{pij} x_{ijk}^{p} \leq \Lambda \qquad \forall k$$

number of patients

$$\sum_{pij} x_{ijk}^{p} \cdot \xi^{p} \leq \Lambda \qquad \forall k$$

chair time

$$\sum_{pij} x_{ijk}^{p} \cdot \nu^{p} \leq \Lambda \qquad \forall k$$

nurse time

$$\sum_{pij} x_{ijk}^{p} \cdot \chi^{p} \leq \Lambda \qquad \forall k$$

complexity

Constraints

- Relationship between scheduling variables and indicators per nurse

$$x_{ijk}^{p} \leq \Theta_k \qquad \forall p, i, j, k$$

- Relationship between scheduling variables and indicators per chair-nurse

$$x_{ijk}^{p} \leq \Omega_k \qquad \forall p, i, j, k$$

- Balance between number of patients in first and second part of nursing shift

$$\sum_{(pij)\in AM} x_{ijk}^{p} + \delta_k^{+} = \sum_{(pij)\in PM} x_{ijk}^{p} + \delta_k^{-} \qquad \forall k$$

Objective Function

$$Min\ \Phi + \sum_k \left(\delta_k^+ + \delta_k^-\right)$$

Where Φ can be chosen as:

- Maximum nurse workload (defined as number of patients, chair time, nurse time or complexity)

$$\Phi = \Lambda$$

- Number of nurses scheduled

$$\Phi = \sum_k \Theta_k$$

- Number of chairs used

$$\Phi = \sum_{jk} \Omega_{jk}$$

The Model in Numbers

- Typical scenario:
  - 40 to 50 patients to be scheduled
  - 8-9 nurses (8-hr shift; 6-hr of effective treatment)
  - 4 chairs per nurse
  - 11-hr workday (8:00 to 19:00) divided in 15′ slots
- Resolution:

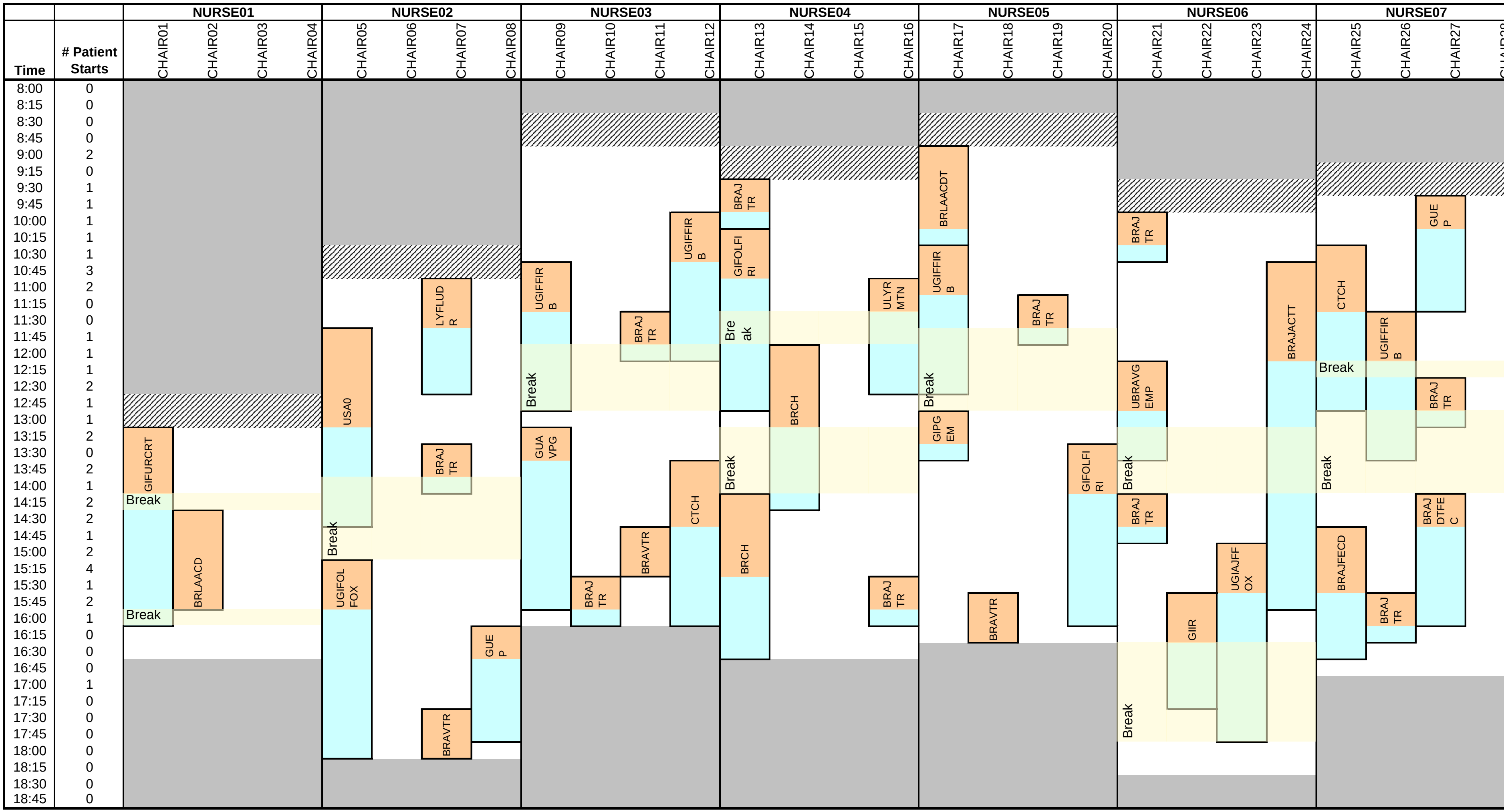
Decision variables:	over 100,000 (most binary)
Constraints:	over 40,000
Solution time:	~1-5′ to optimality (30″ for gap < 5%)
Modeling platform:	GAMS/CPLEX
Database platform:	MS Access
Tool platform:	VBA

Output Report – Nursing Schedule

Time	# Patient Starts	NURSE01	NURSE02	NURSE03	NURSE04	NURSE05	NURSE06	NURSE07
8:00	0							
8:15	0							
8:30	0							
8:45	0							
9:00	2					BRLAACDT (75min)		
9:15	0							
9:30	1				BRAJTR (30min)			
9:45	1							GUEP (30min)
10:00	1			UGIFFIRB (45min)			BRAJTR (30min)	
10:15	1				GIFOLFIRI (45min)			
10:30	1					UGIFFIRB (45min)		CTCH (60min)
10:45	3			UGIFFIRB (45min)			BRAJACTT (90min)	
11:00	2		LYFLUDR (45min)		ULYRMTN (30min)			
11:15	0					BRAJTR (30min)		
11:30	0			BRAJTR (30min)	Break			UGIFFIRB (45min)
11:45	1		USA0 (90min)			Break		
12:00	1			Break	BRCH (75min)			
12:15	1						UBRAVGEMP (45min)	Break
12:30	2							BRAJTR (30min)
12:45	1							
13:00	1					GIPGEM (30min)		
13:15	2	GIFURCRT (60min)		GUAVPG (30min)	Break		Break	Break
13:30	0		BRAJTR (30min)			GIFOLFIRI (45min)		
13:45	2			CTCH (60min)				
14:00	1		Break					
14:15	2	Break			BRCH (75min)		BRAJTR (30min)	BRAJDTFEC (30min)
14:30	2	BRLAACD (90min)						
14:45	1			BRAVTR (45min)				BRAJFECD (60min)
15:00	2						UGIAJFFOX (45min)	
15:15	4		UGIFOLFOX (45min)					
15:30	1			BRAJTR (30min)	BRAJTR (30min)			
15:45	2					BRAVTR (45min)	GIIR (45min)	BRAJTR (30min)
16:00	1	Break						
16:15	0		GUEP (30min)					
16:30	0						Break	
16:45	0							
17:00	1							
17:15	0							
17:30	0		BRAVTR (45min)					
17:45	0							
18:00	0							
18:15	0							
18:30	0							
18:45	0							

		NURSE01	NURSE02	NURSE03	NURSE04	NURSE05	NURSE06	NURSE07
# Patients	40	2	6	7	6	6	6	7
Total Time	39:0	3:0	6:0	6:15	5:45	6:15	6:0	5:45
Booked Time	30:45	2:30	4:45	4:45	4:45	4:30	4:45	4:45
% Booked	79%	83%	79%	76%	83%	72%	79%	83%
Chair Time	72:15	4:30	11:0	12:0	11:0	8:45	13:0	12:0

Output Report – Chair Schedule

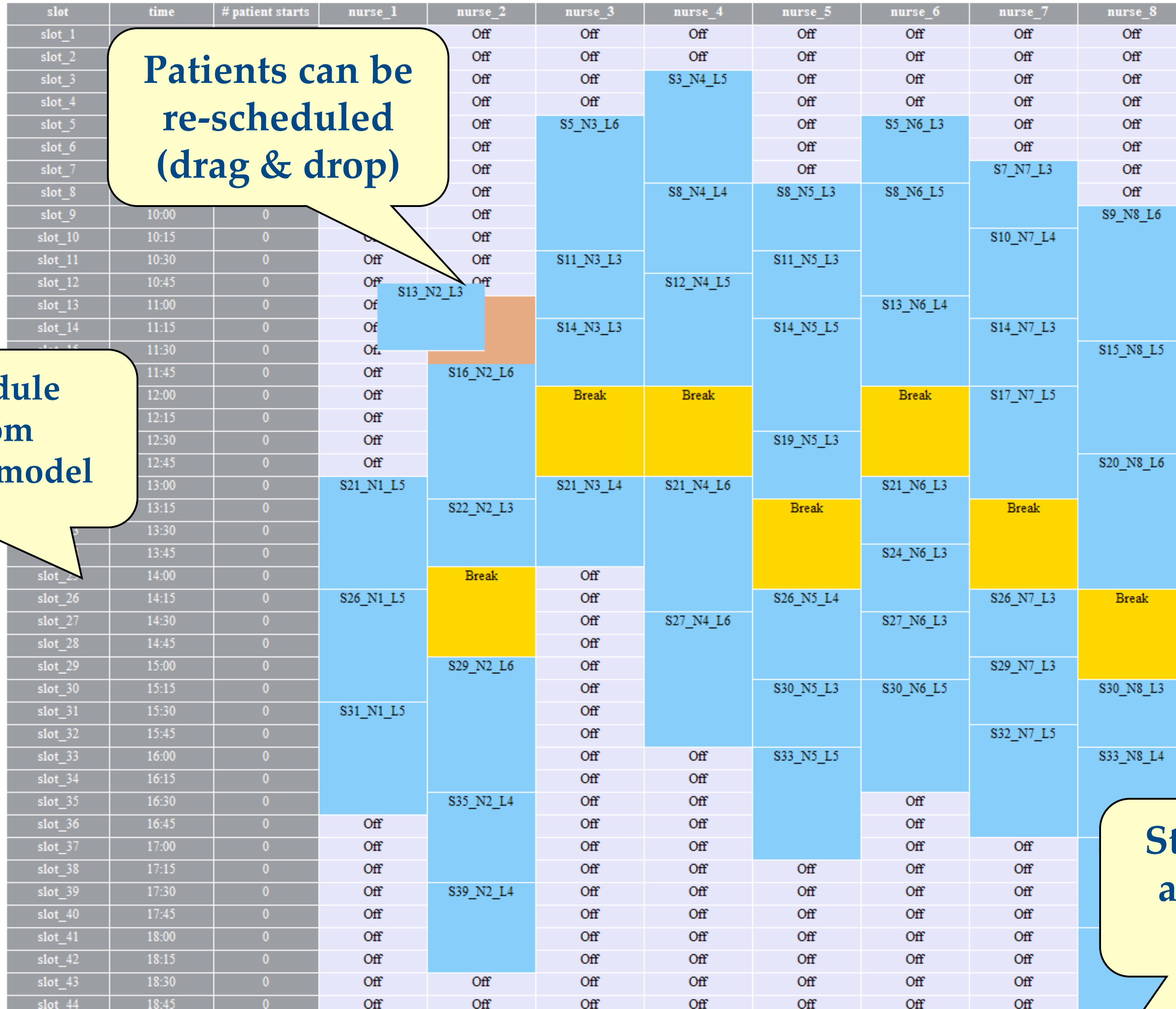


# Patients	1	1	0	0	2	0	3	1	2	1	2	2	3	1	0	2	3	1	1	1	3	1	1	1	2	2	3	0
Nursing time	1:00	1:30	0	0	2:15	0	2:00	0:30	1:15	0:30	1:15	1:45	2:30	1:15	0	1:00	2:30	0:45	0:30	0:45	1:45	0:45	0:45	1:30	2:00	1:15	1:30	0
Chair time	3:00	1:30	0	0	6:00	0	3:15	1:45	5:00	0:45	1:30	4:45	6:00	2:30	0	2:30	4:30	0:45	0:45	2:45	3:00	1:45	3:00	5:15	4:30	3:00	4:30	0

Scheduling Tool Concept

- Visual interface for managers to review and modify schedule
- Initial schedule loaded from optimization model
- Patients can be re-scheduled across nurses
  - Constraints are checked "on the fly" and warnings/error messages reported to user
  - Workload stats are updated after every change
  - Web-based platform

Schedule Modifier Tool Concept



Patients can be re-scheduled (drag & drop)

Initial schedule loaded from optimization model

Stats are updated after changes in schedule

# Patients	46	3	6	4	5	7	7	7	7
Total Time	48:15	3:45	6:30	4:0	6:30	6:30	6:30	6:30	8:0
Booked Time	48:15	3:45	6:30	4:0	6:30	6:30	6:30	6:30	8:0
% Booked	100%	100%	100%	100%	100%	100%	100%	100%	100%
Chair Time	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0	0:0

Discussion

- Implementation plan being developed
- Daily optimization model
  - Requires expert involvement
  - Must interface with system
    - Inputs
    - Outputs
    - Standalone tool
- Ignores variability
- Many inputs are arbitrary now

Overall Concluding Comments

Concluding Remarks

- Just touched the tip of the iceberg of potential applications
- Many challenging optimization (OR) problems arise in healthcare
- They can significantly effect practice both at the operational and strategic levels
- They offer great research potential
- Often solutions cannot be delivered easily so guidelines are necessary
- Researchers must be cognizant of needs of staff and work collaboratively to develop applications