Scheduling Family Medicine Residents to Shifts in Multiple Clinics Using Multi-criteria Optimization Methods

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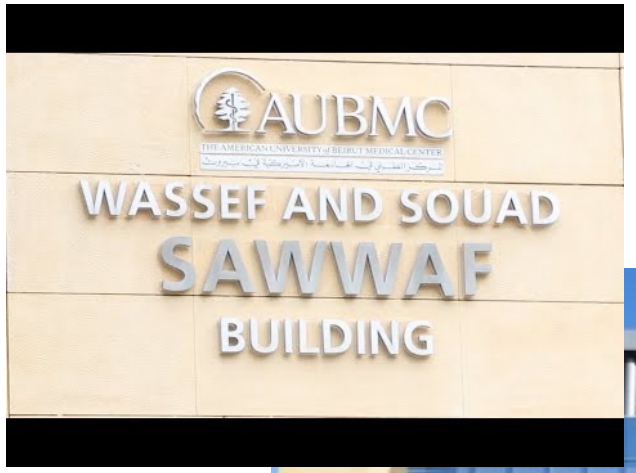
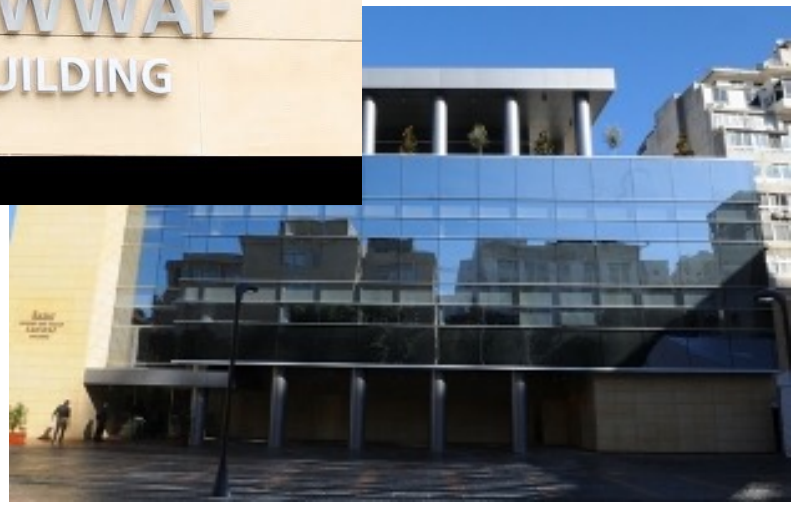
Also thanks to Tim Breckwoldt and David Keller

PROJECT ORIGIN





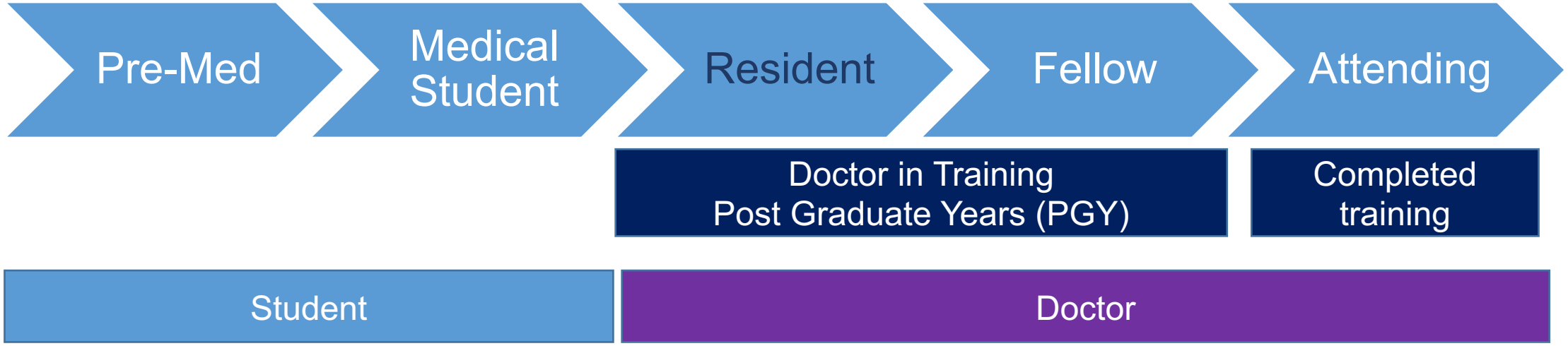
- Dr. MohammadAli H. Jardaly, a CHEPS alum and the 2020-2021 Chief Resident of the Family Medicine residency program at the American University of Beirut Medical Center (AUBMC)

FAMILY MEDICINE

WHAT IS FAMILY MEDICINE (FM)?

- Family Medicine (FM) is the medical specialty that provides continuing, comprehensive health care for the individual and family
- It is a specialty that integrates the biological, clinical and behavioral sciences
- The scope of family medicine encompasses all ages and sexes, each organ system, and every disease entity, with a special focus on the family unit
- Family physicians provide personalized care for the entire person, considering clinical, social and behavioural aspects that impact a person's wellness

MEDICAL TRAINING PATHWAY



FM RESIDENCY PROGRAM AT AUB MEDICAL CENTER

- First FM program in the Arab world, est. 1979
- A 4-year training program, 5–6 residents per year
- Each year, each resident follows a unique sequence of 2- or 4-week *rotations* in different departments outside of FM, to get exposure to subspecialty disciplines
- In addition to work in rotation departments, FM residents always have responsibilities in the FM department clinics
  - Family Medicine Practice Center (FMPC) is the department's main clinic at AUBMC, the "home base"
  - Additional clinic locations include satellites in Beirut and other dedicated clinics within AUBMC, e.g., the flu clinic

PROBLEM STATEMENT

RESIDENTS' SHIFT SCHEDULES

- Example: one week in the life of a 3rd-year resident on a nephrology rotation

	Mon 11/16	Tue 11/17	Wed 11/18	Thu 11/19	Fri 11/20
8.30AM-12.00PM		Nephrology			
1.30-5.00PM	Nephrology				Nephrology
5.00PM-7.30AM					

- Some Nephrology shifts are given a priori; others are added after FM schedule is completed
- For each FM Clinic, a specific location will be given

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5.00PM-7.30AM			Night Shift at AUMBC		

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5.00PM-7.30AM			Night Shift at AUMBC		

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SCHEDULING PRACTICES

- The year is divided into 4-week *blocks*
  - Scheduling is done one block at a time
- Residents are assigned to AM and PM shifts during the weekdays
  - Each assignment specifies a clinic location
- Every day, a resident is assigned to the Night shift
  - This resident gets the following PM and Night shifts off
  - The resident assigned to the Night shift on Saturday or Sunday also covers AM and PM shifts at the FMPC clinic on that day
- Each location has different staffing needs and requirements or preferences for residents in a particular year or rotation

SCHEDULING PROBLEM STATEMENT

- For each day in the block, decide
  - whether and where the resident is working the AM and PM shifts (weekdays)
  - whether the resident is working the Night shift
- in a way that
  - meets clinics' staffing requirements
  - follows various scheduling rules
- with the goal of creating a high-quality schedule, from the perspective of
  - clinics' staffing preferences
  - residents' training, quality of life, and equity

PROJECT GOALS

- The Chief Resident is responsible for creating all residents' daily shift schedules
- Historically, a time-consuming manual process
- Our goals:
  - Formulate a mathematical model of the scheduling problem
  - Implement and document the model as an accessible tool
  - Enable current and future Chief Residents to learn and use the tool independently

PROBLEM FORMULATION

FORMULATION: NOTATION

- R: set of residents
- K: set of clinic locations
- N: set of rotations
  $N = \{\text{FM Internal Medicine, Nephrology, OBGYN, Vacation/Abroad, } \ldots\}$
- D: set of days during the block, $d = 1, 2, \ldots, 28$
  - D^{wd}: all weekdays during the block
  - $v(d)$: day of the week of day d ($v(1) = 1$, i.e., Monday)
  - $w(d)$: week of the block of day d
- AM, PM, Night: shift types

FORMULATION: INPUTS

- For every rotation department $n \in N$,
  - demands on residents' schedules (see formulation)
- For every resident $r \in R$,
  - resident's year in the program
  - rotation for the first and second halves of the block
  - locations where the resident has already worked this year
- For every location $k \in K$,
  - staffing needs for AM and PM shifts on each weekday
  - residents disallowed to work at the location, based on their year
  - if applicable, preferences for residents' year and/or current rotation

FORMULATION: DECISION VARIABLES

- Assignments for AM and PM shifts on weekdays: for all $r \in R, k \in K, d \in D^{\mathrm{wd}}, s \in \{\mathrm{AM}, \mathrm{PM}\}$,

$$x_{rkds} = 1 \text{ if resident } r \text{ is assigned to location } k \text{ on day } d \text{ for shift } s\text{; 0 o/w}$$

- Assignments for night shifts: for all $r \in R, d \in D$,

$$u_{rd} = 1 \text{ if resident } r \text{ is assigned to the Night shift on day } d\text{; 0 o/w}$$

FORMULATION: CONSTRAINTS

- No conflicting assignments:

$$x_{r,\text{not working in FM},ds} + \sum_{k \in K} x_{rkds} = 1, \qquad r \in R, d \in D^{\text{wd}}, s \in \{\text{AM}, \text{PM}\}$$

- No first-year residents ($Y_1 \subset R$) on Night shifts:

$$\sum_{r \in Y_1} \sum_{d \in D} u_{rd} = 0$$

FORMULATION: CONSTRAINTS

- Resident availability:
  - Weekday AM and PM shifts:

$$\sum_{k \in K} x_{rdks} \leq a^{\text{wd}}_{rds}, \qquad r \in R, d \in D^{\text{wd}}, s \in \{\text{AM}, \text{PM}\}$$

  - Night shifts:

$$u_{rd} \leq a^{\text{Night}}_{rd}, \qquad r \in R, d \in D$$

  - Here, a's indicate whether the resident is available for a Family Medicine shift based on their rotation scheduling commitments and any other prior arrangements

FORMULATION: CONSTRAINTS

- A resident can't be assigned to a Night shift and to a PM or Night shift the next day:
  - Sunday through Thursday:

$$u_{rd} + u_{r(d+1)} + \sum_{k \in K} x_{rk(d+1)\mathrm{PM}} \leq 1, \qquad r \in R, d < 28: v(d) \in \{1,2,3,4,7\}$$

  - Friday and Saturday:

$$u_{rd} + u_{r(d+1)} \leq 1, \qquad r \in R, d : v(d) \in \{5,6\}$$

(since daytime shifts on Saturdays and Sundays are handled differently)

FORMULATION: CONSTRAINTS

- Weekly shift bounds for residents: for all $r \in R, w = 1, 2, 3, 4,$

$$\text{lower bound} \leq \sum_{k \in K} \sum_{d \in D^{\text{wd}}: w(d) = w} (x_{rdk\text{AM}} + x_{rdk\text{PM}}) \leq \text{upper bound}$$

  - Bound values depend on the resident's year and rotation
- Locations' staffing: for all $k \in K, d \in D^{\text{wd}}, s \in \{\text{AM}, \text{PM}\}$

$$l_{k,v(d),s} \leq \sum_{r \in R} x_{rkds} \leq u_{k,v(d),s}$$

  - Bound values depend on day of the week, shift, and location

FORMULATION: CONSTRAINTS

- Some locations do not allow residents based on their year:

$$\sum_{r \in Y_i} \sum_{d \in D^{\mathrm{wd}}} (x_{rkd\mathrm{AM}} + x_{rkd\mathrm{PM}}) \leq M(1 - B_{ik}), \qquad i = 1, 2, 3, 4, k \in K,$$

where $B_{ik} = 1$ if residents in year i are not allowed in location k, and 0 o/w, and M is a sufficiently large constant

FORMULATION: CONSTRAINTS

- Odds and ends:
  - Each resident must cover at least one shift per week at the FMPC location (the “home base”), unless they are on vacation or rotation abroad
  - Residents who are on the FM Internal Medicine rotation should not be assigned to Night shifts Sunday through Thursday, so that they are available to see patients at FMPC throughout the week (including PM shifts)
    - ... except the most senior of them gets the Night shift on the last day (Sunday) of the block

FORMULATION: COST FUNCTION

- The cost function is a weighted sum of various metrics of the block's schedule quality:
  - # of times residents work more than one Night shift a week
  - # of times locations get assigned a resident whose year or rotation does not match the clinic's preferences
  - # of locations that a resident has not experienced so far this year
    - "location diversity"; based on input info and this block's schedule
  - # of "excess shifts" assigned beyond the residents' lower bounds
  - Night-shift-points (1 for w/day, 2 for w/end) inequity over the block
    - Defined as the diff. between the largest and smallest point values among residents
    - Smallest value calculation excludes residents ineligible for night shifts
  - Weekly schedule non-uniformity…

WEEKLY SCHEDULE NON-UNIFORMITY METRIC

- Residents prefer consistent schedules from one week to the next during a block
- Thus, we define a metric

$$\sum_{r \in R} \sum_{v=1,\ldots,5} \sum_{s \in \{\text{AM,PM}\}} \sum_{j=1,2,3} y_{rvsj},$$

where, for $r \in R$ and $s \in \{AM, PM\}$,

- $y_{rv(d)s1} \geq \left| x_{rkds} - x_{rk,d+7,s} \right|, \quad d = 1, \ldots, 5, \; k \in K \cup \{\text{not working in FM}\}$
- $y_{rv(d)s2} \geq \left| x_{rkds} - x_{rk,d+7,s} \right|, \quad d = 8, \ldots, 12, k \in K \cup \{\text{not working in FM}\}$
- $y_{rv(d)s3} \geq \left| x_{rkds} - x_{rk,d+7,s} \right|, \quad d = 15, \ldots, 19, \; k \in K \cup \{\text{not working in FM}\}$

Implementation

IMPLEMENTATION BACKGROUND

- Wanted to enable the Chief Residents to use the tool independently
- Didn’t make ANY assumptions on chiefs’ coding skills or knowledge of optimization modeling
- Solution:
  - Use Excel and optimize UI for ease of use
  - Use OpenSolver: a free Excel optimization add-on
  - Make tabs with inputs and outputs easy to navigate and edit
  - Lock cells/tabs with formulas to error-proof tool

IMPLEMENTATION WALKTHROUGH

- The following slides show selected screenshots to illustrate the design and usage of the tool
- Inputs → Run! → Variable, Constraints and Objective implementation calculations are hidden from user → Outputs!
  - The tab containing model variables, constraints, and objective function has 2627 rows

Color code	
	User input; text
	User input; non-negative integer
	User input; restricted input (selection from drop-down menu)
	Do not change; label or non-user adjustable parameter
	Do not change; formulas and calculations

INPUTS: RESIDENTS' AVAILABILITIES BASED ON ROTATIONS

Rotation	FM Clinics (lower bound)	FM Clinics (upper bound)	Rotation availability matrix 0 = unavailable, 1 = available				
			Monday AM	Monday PM	Tuesday AM	Tuesday PM	Wedn Al
Vacation / Elective Abroad	0	0	0	0	0	0	0
Introduction to FM (End of Year)	2	5	1	1	1	1	1
Introduction to FM (6)	2	2	1	1	1	1	1
FM Inpatient - Senior	3	5	0	1	0	1	0
FM Inpatient - Junior	2	5	0	1	0	1	0
FM Clinics	5	6	1	1	1	1	1
ED Adult	1	1	1	0	1	0	1
ED Peds	1	1	1	0	1	0	1

Rotations and the corresponding LBs and UBs on residents' weekly FM shifts

Schedule of a priori commitments in the rotation departments

INPUTS: RESIDENTS' INFO

Residents			Block 13 2020 Data	
Resident #	Name	Year (1,2,3,4)	Rotation #1 (first 2 weeks)	Rotation #2 (second 2 weeks)
1	Marwan Azzam	1	Pediatrics Ward - MGH	Pediatrics Ward - MGH
2	Rita El Tawil	1	Vacation / Elective Abroad	Vacation / Elective Abroad
8	Roxane Assaf	2	FM Inpatient - Junior	FM Inpatient - Junior
9	E.T. Korbani	3	OBGYN	OBGYN
18	Rana El Jarrah	4	Occupational	Occupational
19		0	Vacation / Elective Abroad	Vacation / Elective Abroad

Resident's year in the program and rotation(s) for this block

Resident's past location diversity info

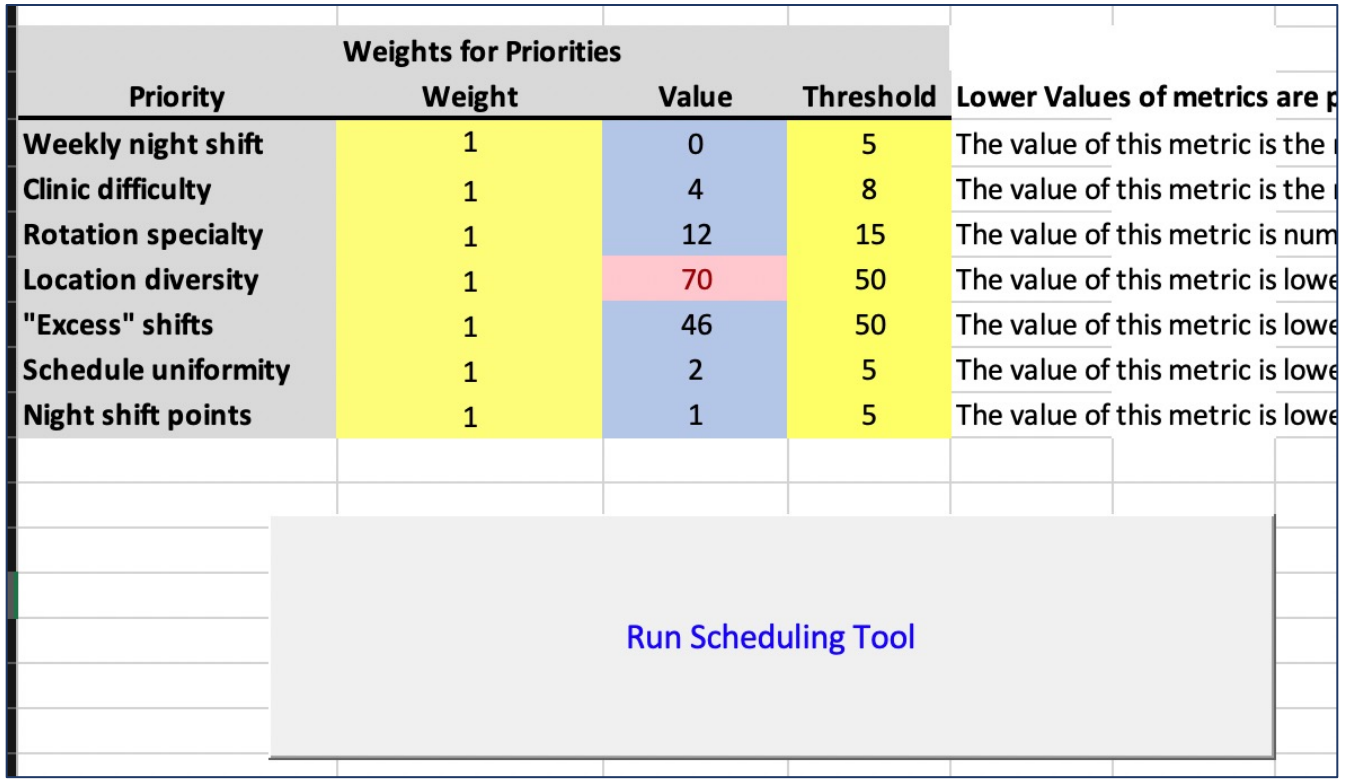
	Location diversity					
eeks)	FMPC	Badaro AM	Badaro PM	Tahadi	KHCC	Mars
MGH	1	0	0	0	0	
road	1	0	0	0	0	
road	1	0	1	0	0	
Adult	1	0	0	1	0	
daro	1	1	0	1	1	

INPUTS: STAFFING NEEDS AT CLINIC LOCATIONS

	Location 1				Location 2		Location 3		Location 4		
Loc / Day	FMPC AM Upper Bound	FMPC AM Lower Bound	FMPC PM Upper Bound	FMPC PM Lower Bound	Badaro AM	Badaro PM	Tahadi AM	Tahadi PM	KHCC AM	KHCC PM	M
Monday	5	2	5	2	1	1	2	0	1	0	
Tuesday	5	2	5	2	0	1	0	0	1	0	
Wednesday	5	2	5	2	1	1	2	0	0	0	
Thursday	5	2	5	2	0	1	2	0	1	0	
Friday	5	2	5	2	0	1	1	0	1	0	
Saturday	0	0	0	0	0	0	0	0	0	0	
Sunday	0	0	0	0	0	0	0	0	0	0	

Upper and lower bounds on staffing at FMPC; exact staffing requirements at other locations

FINAL INPUTS: SCHEDULE QUALITY METRICS' WEIGHTS



	Weights for Priorities			
Priority	Weight	Value	Threshold	Lower Values of metrics are p
Weekly night shift	1	0	5	The value of this metric is the
Clinic difficulty	1	4	8	The value of this metric is the
Rotation specialty	1	12	15	The value of this metric is num
Location diversity	1	70	50	The value of this metric is lowe
"Excess" shifts	1	46	50	The value of this metric is lowe
Schedule uniformity	1	2	5	The value of this metric is lowe
Night shift points	1	1	5	The value of this metric is lowe

Adjust the weights of the quality metrics and hit Run!

OUTPUTS: WEEKDAY SCHEDULE

	FMPC		Badaro		Tahadi	
	AM	PM	AM	PM	AM	PM
Mondays	Mohammad Srour (16,23,,) Nadim-Nicolas Ghanem (16,23,30,7) Mohammad-Ali Jardaly (16,23,30,7) M. Ramadan M (16,23,30,7)	Jad El Khoury (16,23,30,7) Maria Tanielian (16,23,30,7)	Lea Feghali (16,23,30,7)	Roxane Assaf (16,23,30,7)	M. Ibrahim (16,23,30,7) C. Saade (16,23,30,7)	
Tuesdays	E.T. Korbani (17,24,1,8) M. Ramadan M (17,24,1,8)	Marwan Azzam (17,24,1,8) G. Khairallah (17,24,1,8)		Roxane Assaf (17,24,1,8)		
Wednesdays	Mohammad Srour (18,25,,) Lewaa Shujaa (18,25,2,9) E.T. Korbani (18,25,2,9)	Roxane Assaf (18,25,2,9) C. Saade (18,25,2,9)	Mohammad Ahmed (18,25,2,9)	G. Khairallah (18,25,2,9)	Lea Feghali (18,25,2,9) Mohammad-Ali Jardaly (18,25,2,9)	

OUTPUTS: NIGHT SCHEDULE

Block 13 2020 Night Shift Schedule		
Day	**Date**	**Resident**
Monday	November 16, 2020	E.T. Korbani
Tuesday	17-Nov	Jad El Khoury
Wednesday	18-Nov	Nadim-Nicolas Ghanem
Thursday	19-Nov	C. Saade
Friday	20-Nov	Roxane Assaf
Saturday	21-Nov	G. Khairallah
Sunday	22-Nov	M. Ibrahim
Monday	23-Nov	E.T. Korbani
Tuesday	24-Nov	Mohammad Ahmed
Wednesday	25-Nov	Nadim-Nicolas Ghanem
Thursday	26-Nov	C. Saade
Friday	27-Nov	Roxane Assaf
Saturday	28-Nov	Jad El Khoury
Sunday	29-Nov	Lea Feghali
Monday	30-Nov	E.T. Korbani
Tuesday	1-Dec	Maria Tanielian
Wednesday	2-Dec	E.T. Korbani
Thursday	3-Dec	Nadim-Nicolas Ghanem
Friday	4-Dec	Roxane Assaf

IMPLEMENTATION: ROOM FOR GROWTH AND PROGRAM CHANGES

Residents			Block 13 2020 Data	
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Tool can accommodate up to 30 residents!

IMPLEMENTATION: ROOM FOR GROWTH AND PROGRAM CHANGES

Location 7		Location 8	
Flu AM	Flu PM	Extra AM	Extra PM
1	1	0	0
1	1	0	0
1	1	0	0
1	1	0	0
1	1	0	0
0	0	0	0
0	0	0	0

- An extra clinic location can be added
- Or, if an existing location closes, can set staffing requirements to 0 without modifying tool

IMPLEMENTATION: ROOM FOR GROWTH AND PROGRAM CHANGES

	Tahadi	KHCC	Marsa	Zarif	Flu	Extra
PGY1					1	1
PGY2	0	1	1	1	0	1
PGY3				1	0	1
PGY4						

"0" indicates that residents of the corresponding year are allowed to work in the corresponding clinic

"1" indicates that residents of the corresponding year are not allowed to work in the corresponding clinic

Clinic location access to residents based on their year can be opened or closed

CONCLUSIONS

- MohammadAli used evolving versions of the tool as part of his scheduling process as the Chief Resident in the first half of 2021, giving us feedback
- At the end of his term, he recorded a video walkthrough of the tool from an M.D.'s point of view for the incoming Chiefs
  - The new co-Chiefs learned to use the tool with no input from us, and minimal help from MohammadAli
  - "We want to let you know that the tool you have prepared is amazing and it facilitated our schedule preparation and helped us put less effort and time on it." (Dr. Maria Tanielian)
- Current conditions in Beirut are difficult, making the work of healthcare providers, including consistent scheduling, very hard
  - We hope things get better in Lebanon soon
  - If needed, the model and the tool can be modified

Thank you!