Patient and Equipment Transport Planning at the UVA Medical Center: Staffing Decisions Using Mathematical Programming

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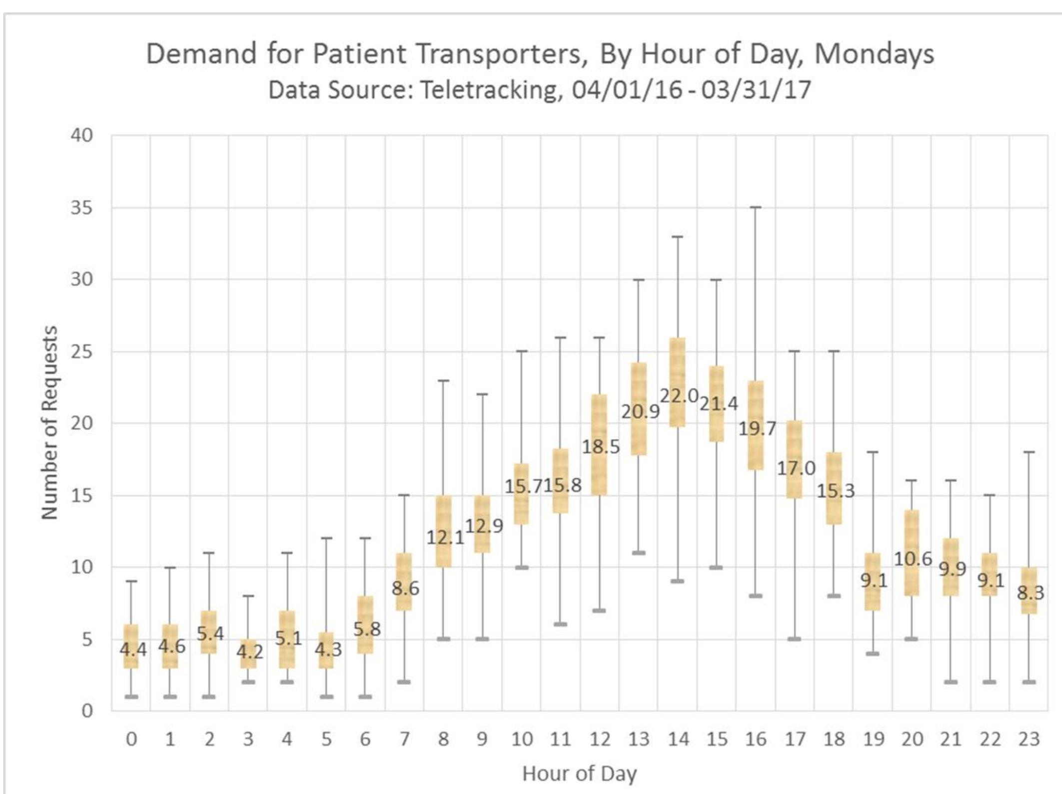
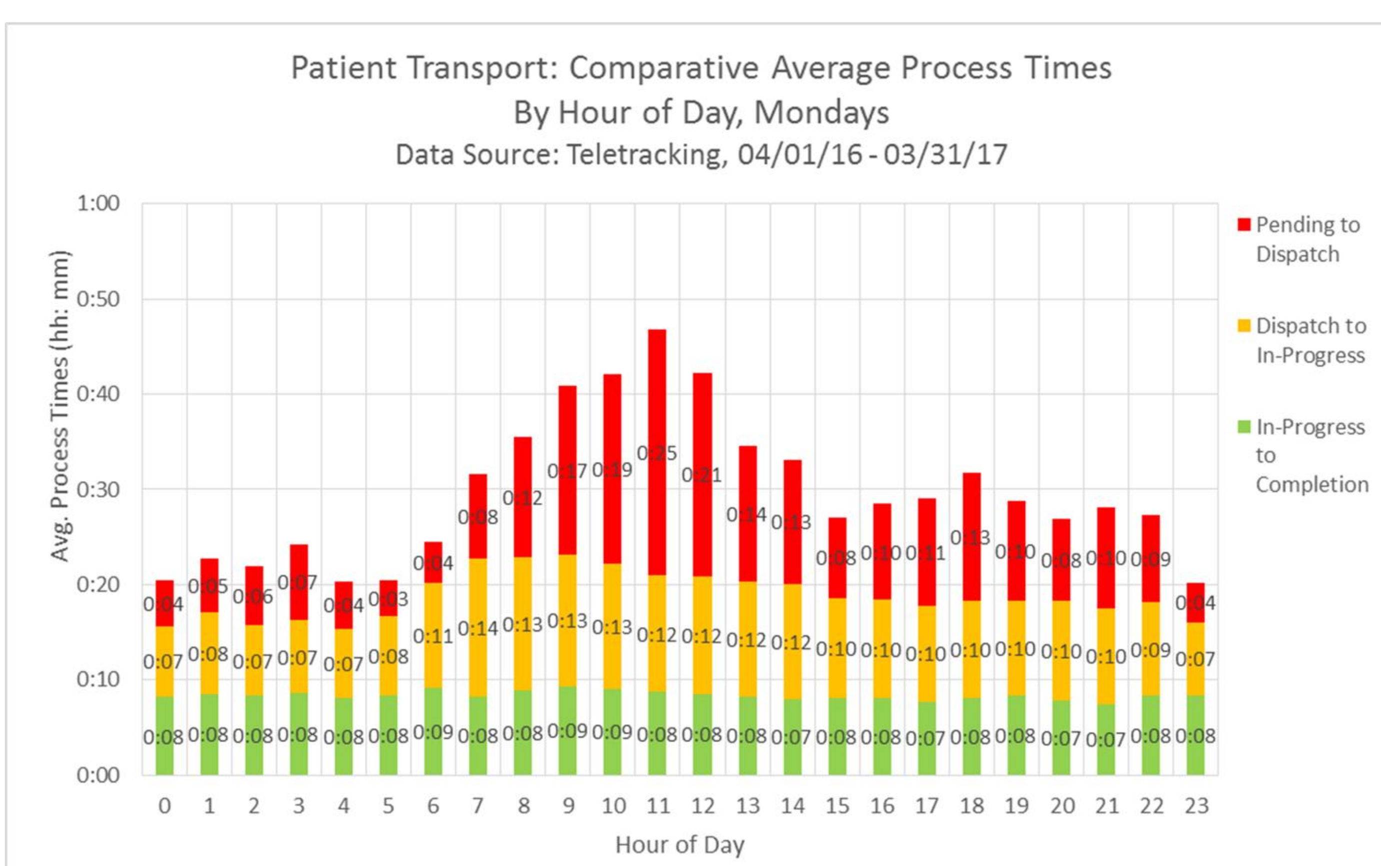
SUMMARY: The University of Virginia Medical Center (UVAMC) requires a quarter of a million patient and equipment transports within a calendar year. Staffing and scheduling decisions are critical in ensuring that both patients and equipment are delivered safely, on time, on a consistent basis. We developed a staffing model using mathematical programming that accommodates fluctuations in demand for patient and equipment transports, and balances out staff workload within a two-week planning horizon. The model enables decision-makers to determine the minimum number of transporters needed to accommodate a selected demand level, based on a chosen target efficiency rate (number of transport trips per hour).

Performance Measurement



① We began by conducting statistical analyses of demand for patient and equipment transports, identifying patterns, variances, and capacity bottlenecks by hour of day, day of week, and geographical origin/destination. This was refined by leveraging learnings from prior workflow analyses conducted by an interdisciplinary team.



② Analyses showed that the time spent waiting to accept a transport request ("pending to dispatch") is influenced by a) the number of staff working (a *structural* variable), as well as b) the readiness of the patient/equipment being transported once the transporter arrives (a *process* variable). We wanted to reduce or eliminate this wait time by matching staffing patterns with fluctuations in demand.

Systems Modeling

SHIFT s (s_1,…,s_6)	
s_1	7:00 - 15:30
s_2	8:00 -16:30
s_3	10:00 - 18:30
s_4	12:30 - 21:00
s_5	15:00 - 23:30
s_6	23:00 - 7:30

		BLOCK PATTERN b (b_1,…,b_{10}); O = working, X = off									
		b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}
DAY OF WEEK	Su_2	O	O	O	O	O	X	X	X	X	X
	M_1	X	X	O	O	O	O	O	O	O	O
	T_1	O	O	X	X	O	O	O	O	O	O
	W_1	O	O	O	O	X	O	O	X	O	O
	R_1	O	O	O	O	O	O	O	O	X	X
	F_1	O	O	O	O	O	X	X	O	O	O
	Sa_1	X	X	X	X	X	O	O	O	O	O
	Su_1	X	X	X	X	X	O	O	O	O	O
	M_2	O	O	O	O	O	O	O	X	X	O
	T_2	O	O	O	O	O	X	O	O	O	X
	W_2	O	X	O	O	O	O	X	O	O	O
	R_2	X	O	O	X	O	O	O	O	O	O
	F_2	O	O	X	O	X	O	O	O	O	O
	Sa_2	O	O	O	O	O	X	X	X	X	X

③ Our goal was to determine the number and type of transporters needed for each shift and block pattern. Based on prior work, we identified six shift schedules and ten block patterns that would be the foundation of the staffing model. These were chosen to accommodate historic preferences, as well as to minimize the likelihood of absences, which have a significant impact on wait times.

Let:

$x_{s,b}$ = number of equipment-only transporters assigned to time slot s and block b;
$y_{s,b}$ = number of patient-only transporters assigned to time slot s and block b;
$z_{s,b}$ = number of flexible (both eqpt/pat) transporters assigned to time slot s and block b;
$EqDemAvg_{t,d}$ = average equipment demand for time period t and day d;
$PatDemAvg_{t,d}$ = average patient demand for time period t and day d;
EffEq = efficiency of equipment-only trips per (half) hour;
EffPat = efficiency of equipment-only trips per (half) hour;
$W_{s,b,t,d}$ = binary matrix that shows if transporter assigned to shift s and block d is working (=1) on time slot t on day d;
s = 1 to 6, b = 1 to 10, t = 1 to 48 (half hour periods), d = 1 to 14 (two week planning horizon);

Objective: Minimize $\sum_s \sum_b x_{s,b} + \sum_s \sum_b y_{s,b} + \sum_s \sum_b z_{s,b}$

subject to:

$$\sum_s \sum_b (x_{s,b} * W_{s,b,t,d}) + \sum_s \sum_b (z_{s,b} * W_{s,b,t,d}) \geq EqDemAvg_{t,d}/EffEq \text{ for all (t,d);}$$
$$\sum_s \sum_b (y_{s,b} * W_{s,b,t,d}) + \sum_s \sum_b (z_{s,b} * W_{s,b,t,d}) \geq PatDemAvg_{t,d}/EffPat \text{ for all (t,d);}$$

:

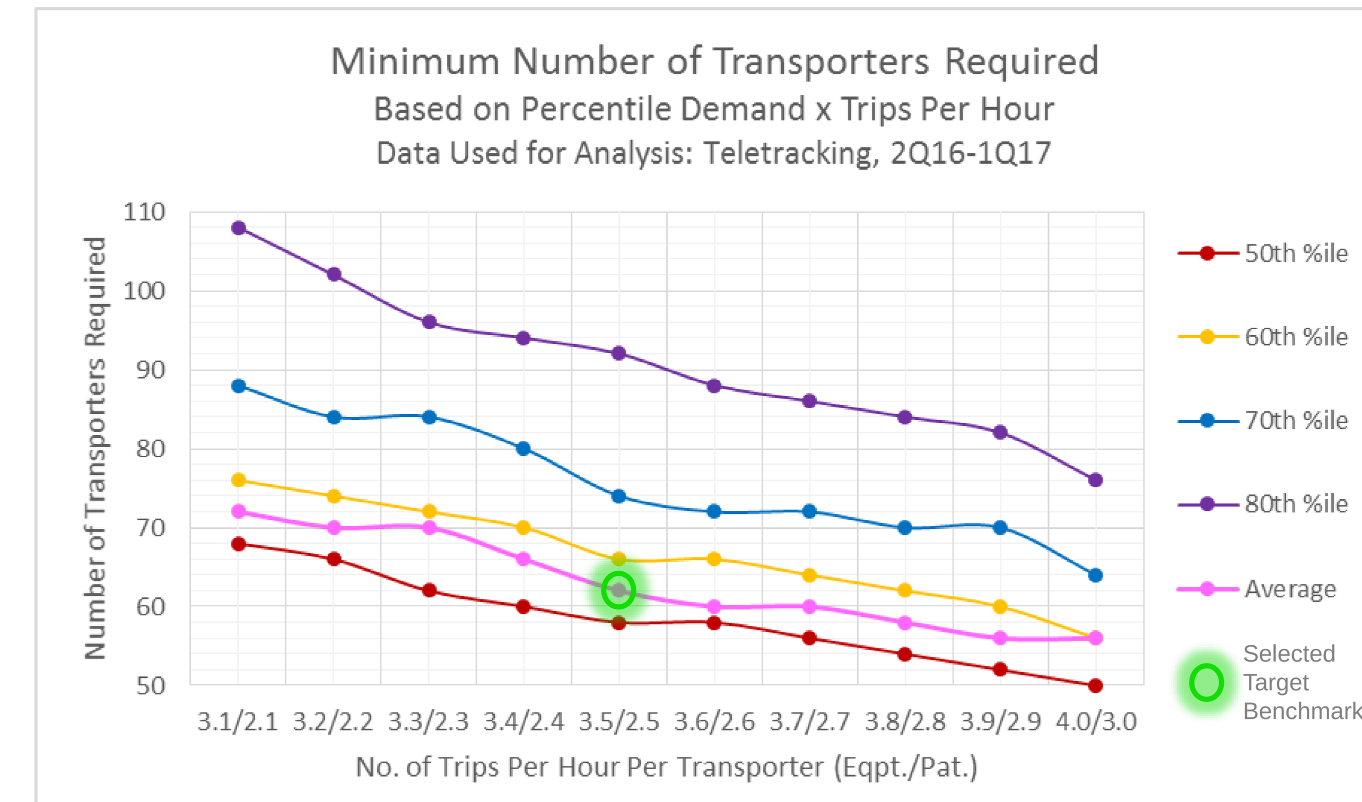
$$\sum_s \sum_b (x_{s,b} * W_{s,b,t,d=1}) + \sum_s \sum_b ((z_{s,b} * W_{s,b,t,d=1})/2) = \sum_s \sum_b (x_{s,b} * W_{s,b,t,d=8}) + \sum_s \sum_b (z_{s,b} * W_{s,b,t,d=8}) \text{ for all t;}$$
$$\sum_s \sum_b (y_{s,b} * W_{s,b,t,d=1}) + \sum_s \sum_b ((z_{s,b} * W_{s,b,t,d=1})/2) = \sum_s \sum_b (y_{s,b} * W_{s,b,t,d=8}) + \sum_s \sum_b (z_{s,b} * W_{s,b,t,d=8}) \text{ for all t;}$$

:

(more constraints – there are too many to fit in this poster!)

④ A mixed-integer programming model was developed using GAMS software to determine the number of transporters needed for specific shifts and block patterns. The objective was to minimize the number of transporters needed to meet demand per time period, workload balance (i.e., transporters need to work every other weekend), and prioritization (i.e., patients before equipment) constraints.

Change Management



⑤ We generated efficiency curves based on structural and process benchmarks that enabled decision-makers to select targets that meet explicit priorities (i.e., staffing to meet average demand, patients first before equipment). Senior leaders opted to staff at average demand, and set benchmarks for both patient and equipment transports (3.5/2.5 trips per hour for equipment/patient transports).

NUMBER OF REQUIRED TRANSPORTERS BY TYPE, SHIFT, AND BLOCK PATTERN

Equipment-Only Transporters		b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}	SubTotal
	s_1	2		2		1	2			2		9
	s_5	2			1	2		2		2		9
	s_6	1	1	1			1		1			5
	SubTotal	*5*	*1*	*3*	*1*	*3*	*3*	*2*	*1*	*4*	*0*	*23*

Patient-Only Transporters		b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}	SubTotal
	s_1		1		2	1			1		2	7
	s_2	1								1		2
	s_3		2		1				2		1	6
	s_5	1			1	2		2		1		7
	s_6	1				2		2				5
	SubTotal	*3*	*3*	*0*	*4*	*5*	*0*	*4*	*3*	*2*	*3*	*27*

Flexible Transporters		b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}	SubTotal
	s_1	1						2		1		4
	s_5	1								1	2	4
	s_6		1						1	2		4
	SubTotal	*2*	*1*	*0*	*0*	*0*	*0*	*2*	*1*	*4*	*2*	*12*

Total Number of Transporters		b_1	b_2	b_3	b_4	b_5	b_6	b_7	b_8	b_9	b_{10}	Total
	s_1	3	1	2	2	2	2	2	1	3	2	20
	s_2	1	0	0	0	0	0	0	0	1	0	2
	s_3	0	2	0	1	0	0	0	2	0	1	6
	s_4	0	0	0	0	0	0	0	0	0	0	0
	s_5	4	0	0	2	4	0	4	0	4	2	20
	s_6	2	2	1	0	2	1	2	2	2	0	14
	Total	**10**	**5**	**3**	**5**	**8**	**3**	**8**	**5**	**10**	**5**	**62**

⑥ Model results detail the number and type of transporters required per shift and by block pattern to meet all identified constraints. Structural changes (i.e., hiring more transporters) will be explored once waiting times have been eliminated through process improvements. Model extensions include determining where to "zone" transporters to minimize response and travel time.

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