Capacity Planning Tool

3	Flow Calculation	Split Flow Inpatient Transitional Care
4	LOU/LOH/LOT	Time Stamps
5	Capacity Planning	Target Utilization
6	Staffing Profile	Integer Effect

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Analysis Goals

- With this tool, the user will be able to answer the question: “How much space is required in each area of my split flow network?”
  - Space will defined as providers or physical patient capacity, depending upon the area.

- This decision is based on acuity split, area arrival rates, service times, and target performance measures.

Patient Safety Performance Measures

Estimated Using Queuing Theory [1][2][3]

- Server Utilization (ρ)
  - The average percent of time a resource is “busy”.
  - Bed utilization is the average percent of time a bed is occupied by a patient.
  - Provider utilization is average percent of time spent in direct patient care.
- Wait in Queue (Wq)
  - The average length of time a patient will spend *waiting* for service in an area before starting service.
- Full/Busy Probability (p_c)
  - The fraction of arriving patients who must wait in an area until a resource becomes available. The table below defines resources by area.

Area	Resource Being Capacitated	Interpretation of Full/Busy Probability (p_c)
Quick Look	Provider	The average fraction of time all providers are busy.
Intake/Discharge	Provider	The average fraction of time all providers are busy.
Results Waiting	Space	The average fraction of time that all spaces are full.
IP_{ED}	Space	The average fraction of time that all spaces are full.
Inpatient Transitional Care	Space	The average fraction of time that all spaces are full.

Tool 5 Calculations[4]

- Utilization (ρ): $\rho = \dfrac{\lambda * LOS}{c}$
- Expected wait time in queue (Wq): $Wq = \left(\dfrac{(\lambda * LOS)^c}{c!\dfrac{c}{LOS}(1-\rho)^2} \right) p_0 * \left(\dfrac{C_s^{\,2} + C_a^{\,2}}{2} \right)$

  where: $p_0 = \left(\sum_{n=0}^{c-1} \dfrac{(\lambda * LOS)^n}{n!} + \dfrac{(\lambda * LOS)^c}{c!(1-\rho)} \right)^{-1}$

- Full/Busy probability (p_C): $p_c = \dfrac{\dfrac{(\lambda * LOS)^c}{c!}}{\sum_{i=0}^{c} \dfrac{(\lambda * LOS)^i}{i!}}$

Notation Key:
LOS = {LOU, LOH, or LOT}
c = number of area servers
λ = area arrival rate
Cs, Ca = Coefficient of variation of the service and arrival processes, respectively

- Door-to-Doc (D2D) time:

$$D2D\ time = Wq_{QUICK\ LOOK} + LOS_{QUICK\ LOOK} + \boxed{(f_1 + f_2)}\left(travel_{QUICK\ LOOK \rightarrow IP_{ED}} + Wq_{IP_{ED}}\right) + \boxed{(f_3 + f_4 + f_5)}\left(travel_{QUICK\ LOOK \rightarrow INTAKE} + Wq_{INTAKE}\right)$$

Fraction of lower acuity patients ($f_3 + f_4 + f_5$)

Fraction of higher acuity patients ($f_1 + f_2$)

Tool 5 Input Data

- Arrivals per hour to each location in the Split ED – **3**

INPUT	Quick Look	Intake/Discharge	Results Waiting	IP_{ED}	Inpatient Transitional Care
Arrivals/Hr:	12.62	23.08	11.27	3.36	2.78

- Mean LOS and coefficient of variation in each location:
  - Tool **4** provides inputs for Results Waiting, IP_{ED}, and Admit Hold
  - Defaults can be used in Registration and OP_{ED}

	INPUTS		
Area	Number of Servers Required	Average Time (min.)	Coefficient of Variation
Quick Look	2	7.5	0.19
Intake/Discharge	6	11.3	0.37
Results Waiting	30	120.0	1.00
IP_{ED}	20	238.0	0.71
Inpatient Transitional Care	10	131.0	1.60

From **4**

- Travel times (new data): Quick Look to OP_{ED} and Quick Look to IP_{ED}

INPUT:	
Travel time from Quick Look to OP_{ED} (min.) =	5.0
Travel time from Quick Look to IP_{ED} (min.) =	5.0

The EXCEL® Tool 5

Purpose: Estimate, using queuing theory, patient-safe capacities in each split flow area.

INPUT	Quick Look	Intake/Discharge	Results Waiting	IP_{ED}	Inpatient Transitional Care	From 3
Arrivals/Hr:	12.62	23.08	11.27	3.36	2.78	

	INPUTS			**----OUTPUTS----**		
Area	Number of Servers Required	Average Time (min.)	Coefficient of Variation	Avg. Server Utilization (ρ)	Avg. Wait in Queue (Wq) (min)	Full / Busy Probability (p_C)
Quick Look	2	7.5	0.19	78.9%	6.40	32.6%
Intake/Discharge	6	11.3	0.37	72.1%	1.42	14.1%
Results Waiting	30	120.0	1.00	75.1%	1.51	2.5%
IP_{ED}	20	238.0	0.71	66.6%	1.67	2.2%
Inpatient Transitional Care	10	131.0	1.60	60.7%	6.39	4.5%

From 4

DOOR-TO-DOC TIMES:

INPUT:	
Travel time from Quick Look to OP_{ED} (min.) =	5.0
Travel time from Quick Look to IP_{ED} (min.) =	5.0

← Travel time input

OUTPUT:		
Average Lower Acuity Door-to-Doc Time =	20.3	Minutes
Average Higher Acuity Door-to-Doc Time =	20.6	Minutes
Overall Average Door-to-Doc Time =	20.3	Minutes

3 Flow Calculation — Split Flow / Admit Hold
4 LOU/LOH/LOT — Time Stamps
5 Capacity Planning — Target Utilization
6 Staffing Profile — Integer Effect

Iterating on the Number of Servers

- After input data is entered, you can allocate servers to each area
- More servers means better performance measures and better patient safety, but more expense
- Select scenarios that best balance capacity costs and patient safety
  - Utilization = 70% usually provides good balance and starting point
  - Utilization cell goes RED for $\rho \geq 100\%$ implying not enough servers

	INPUTS			----OUTPUTS----		
Area	Number of Servers Required	Average Time (min.)	Coefficient of Variation	Avg. Server Utilization (ρ)	Avg. Wait in Queue (W_q) (min)	Full / Busy Probability (p_c)
Quick Look	2	7.5	0.19	78.9%	6.40	32.6%
Intake/Discharge	6	11.3	0.37	72.1%	1.42	14.1%
Results Waiting	30	120.0	1.00	75.1%	1.51	2.5%
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Adjust these fields to achieve desirable performance measures

“One-up, One-down” Summary Table

- Once acceptable service levels are chosen, the ‘one-up, one-down’ table can be a useful summary of results for discussion.
- In each area, add one server and note results, then subtract one server and note results. The table includes all three:

Area	Volume/Hr	Average LOU (min.)	Number of Servers	Utilization	Waiting Time (min.)	Full / Busy Probability
Quick Look			1 server	>100%		
Quick Look	12.62	7.5	**2 servers**	78.9%	6.40	32.6%
Quick Look			3 servers	52.6%	0.73	14.6%
Intake/Discharge			5 docs, 15 rooms	86.9%	6.53	23.0%
Intake/Discharge	23.08	11.3	**6 docs, 18 rooms**	72.4%	1.42	14.3%
Intake/Discharge			7 docs, 21 rooms	62.1%	0.44	8.1%
Results Waiting			29 spaces	77.7%	2.55	3.4%
Results Waiting	11.27	120.0	**30 spaces**	75.1%	1.51	2.5%
Results Waiting			31 spaces	72.7%	0.89	1.8%
IP_{ED}			19 beds	74.0%	3.25	4.9%
IP_{ED}	3.36	238.0	**20 beds**	70.1%	1.67	3.3%
IP_{ED}			21 beds	66.6%	0.84	2.2%
Inpatient Transitional Care			9 beds	67.4%	16.44	7.8%
Inpatient Transitional Care	2.78	131.0	**10 beds**	60.7%	6.39	4.5%
Inpatient Transitional Care			11 beds	55.2%	2.50	2.4%

M/G/c results

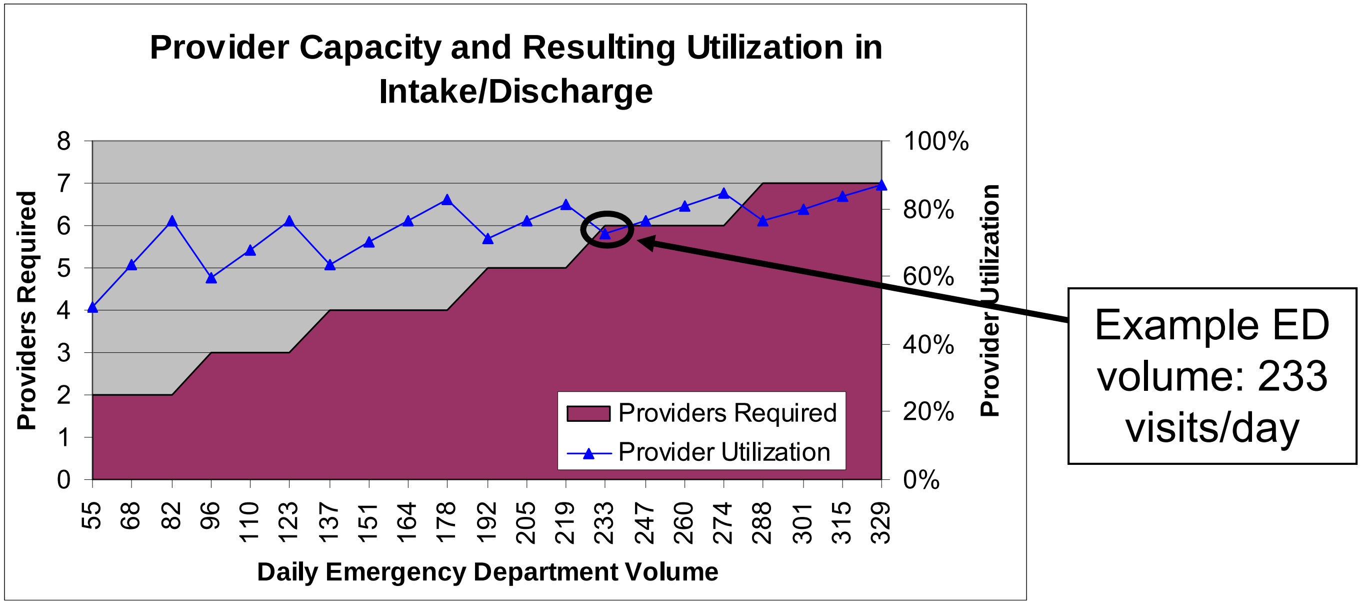
M/G/c/c results

The shaded numbers are used to estimate Average D2D time:

$$D2D\,time = 6.42 + 7.5 + (0.28\% + 8.28\%)(5 + 1.67) + (68.73\% + 20.53\% + 2.18\%)(5 + 1.42) = \boxed{20.3\ minutes}$$

Summary / Next Steps

- We can look at capacity requirements over any range of volumes



- 3:1 Room:Provider ratio rule in Intake provides areas for patient staging, while, from a queuing perspective, a 2:1 ratio provides low room overflow probabilities.
- Now we can use Tool 6 to see how all areas should be staffed.

References

[1] contains the theory of estimating performance measures in a queue.
[2] discusses its use in this Toolkit.
[3] uses queuing theory in a nine-node split ED.
[4] presents the Allen-Cunneen approximation for wait in queue calculations

[1] Gross D, Harris CM. *Fundamentals of Queueing Theory, 3rd edition.* New York: John Wiley and Sons, Inc.; 1998.

[2] Roche KT, Cochran JK. Improving patient safety by maximizing fast-track benefits in the emergency department – A queuing network approach. *Proceedings of the 2007 Industrial Engineering Research Conference*, eds. Bayraksan G, Lin W, Son Y, Wysk R. 2007. pg. 619-624.

[3] Cochran JK, Roche KT (submitted). A multi-class queuing network analysis methodology for improving hospital emergency department performance, *Computers and Operations Research* 2007.

[4] Allen AO. *Probability, Statistics, and Queueing Theory with Computer Science Applications.* London: Academic Press, Inc.; 1978.