Computer Simulation in Healthcare

Overview

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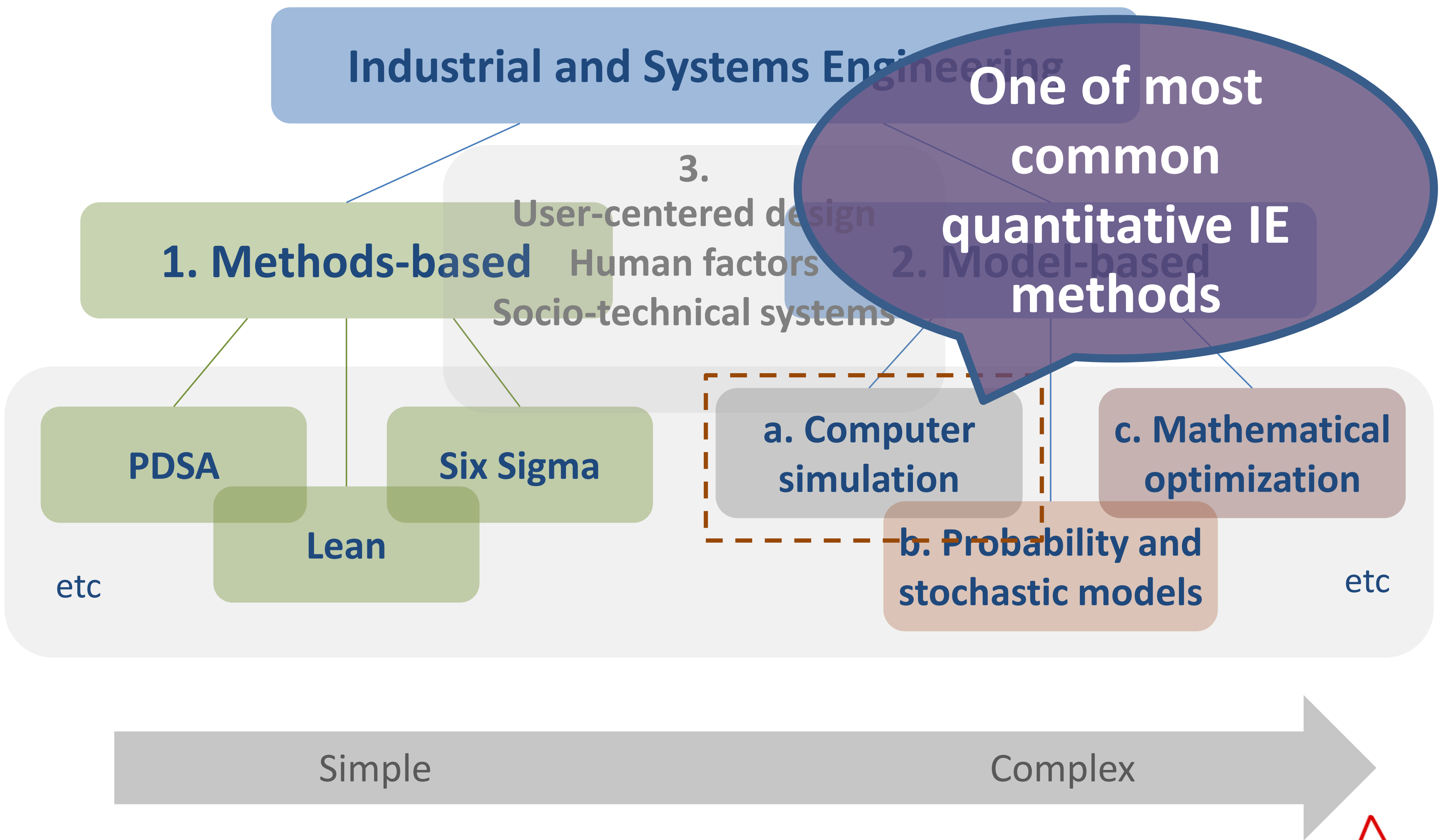
Intro

Uses

Types

What is systems engineering?



Types of simulation models

Type of model	Description	Example(s)
Monte Carlo models	Randomness & complex logic, but no time dependencies	Gambling games Statistical analysis
Discrete event models (DES)	System state changes at discrete points in time due to arrivals, departures, & other process logic	Manufacturing flow Queuing models
Cellular automata models	Adjacency transitions (from 1 cell or geographic area to another)	Population growth Disease spread (flu)
Continuous (CES) & mixed discrete-continuous	System state is continuously changing (mixed models have discrete & continuous changes)	Oil refinery, inputs & withdrawals Sauna temperature
System dynamics models (aka CES)	System interactions represented as continually changing relationships	Economy, money flows, policy studies
Agent based models	Entities in system act independently (as 'agents') based on current system state	Human behavior

What is a model…?

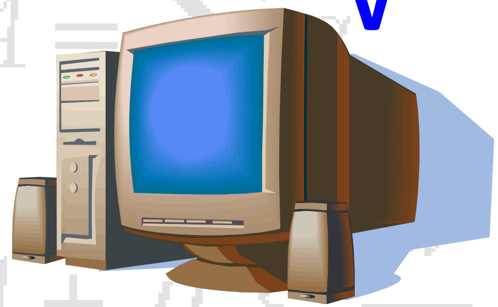
a.

X

b.

X

c. √



d.

- An artificial representation of the real world
- Perhaps idealized, simplified; hopefully useful

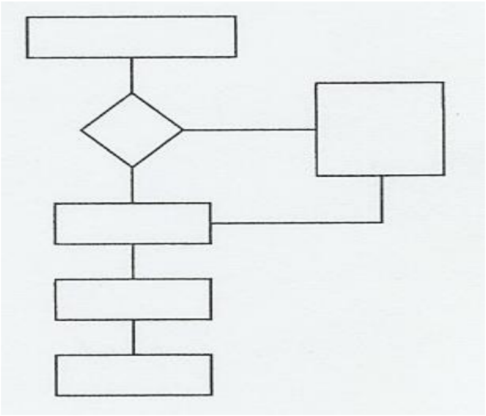
"All models are wrong, some are useful"

- G.E.P. Box

What is a simulation?

Simulation basic ideas

1 Process Logic



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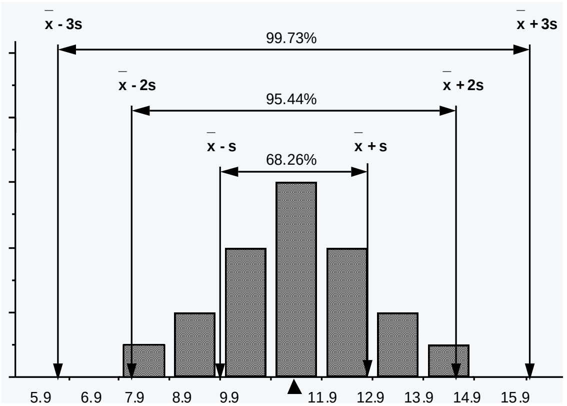
2 Process Variation



Process Performance

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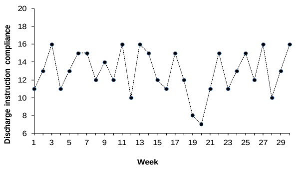
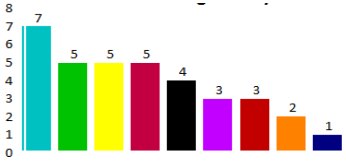
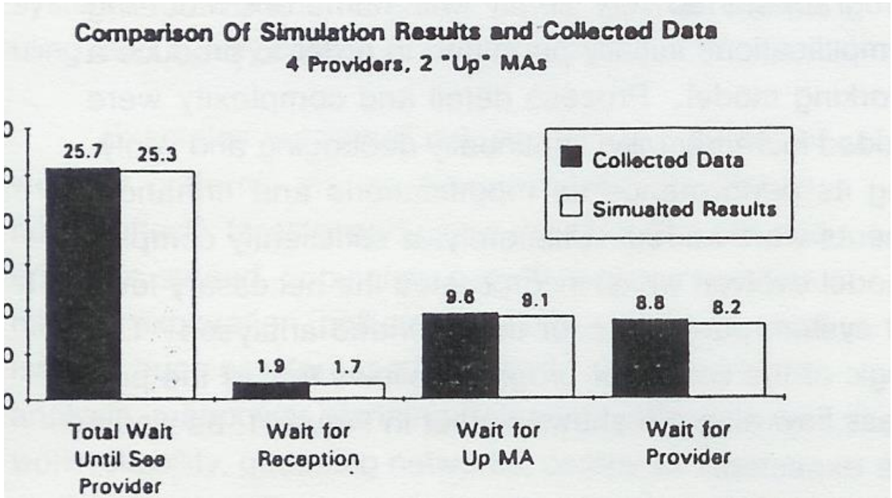


Case	Table ("replication")			Mean	SD	95% conf interval
	1	2	3			
1						
2						
3						
4						

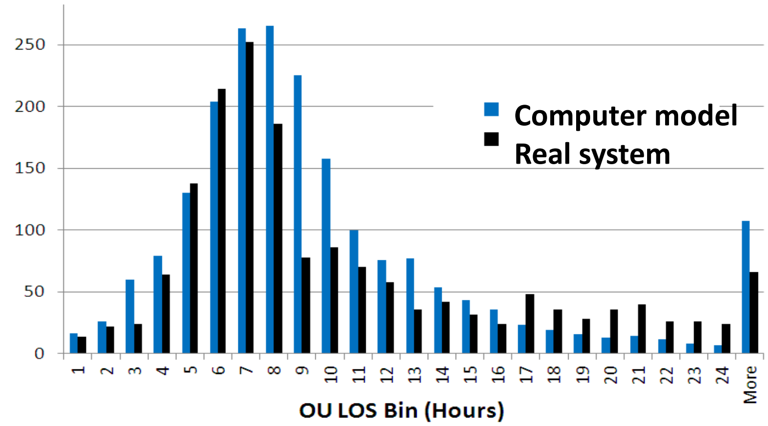


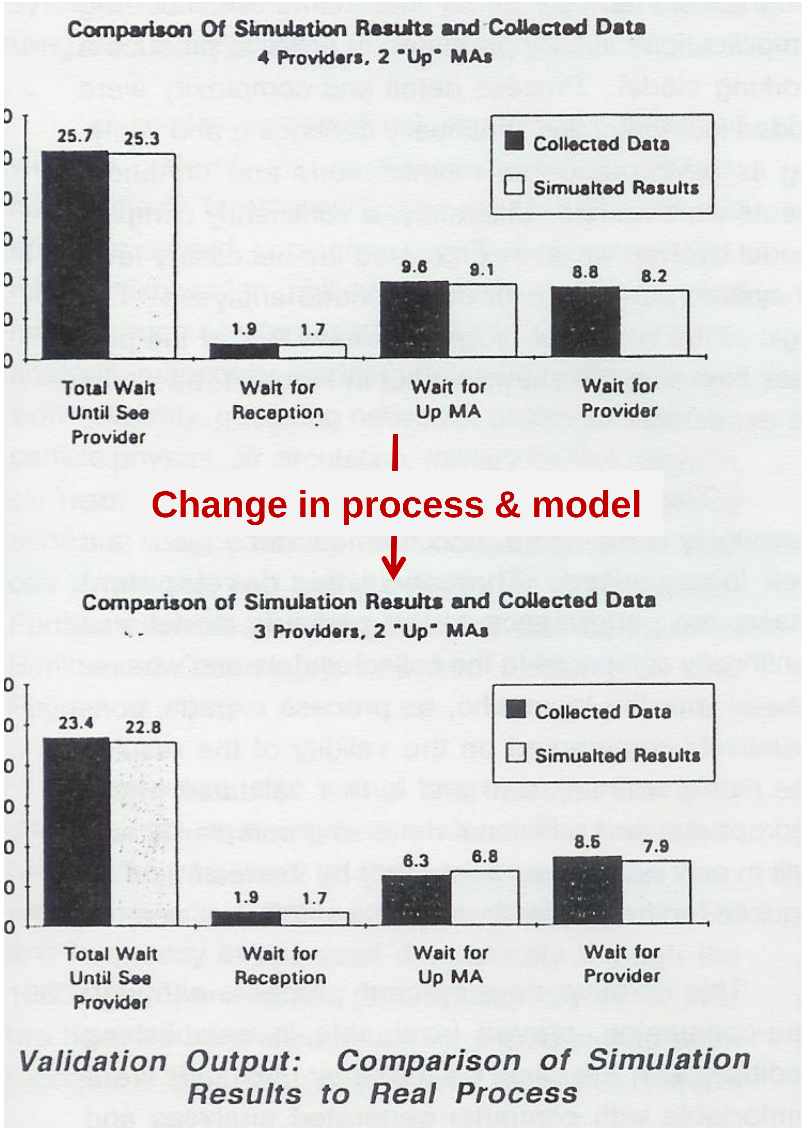
Model accuracy - Simulation vs real data

Pediatric clinic simulation



Observation unit simulation





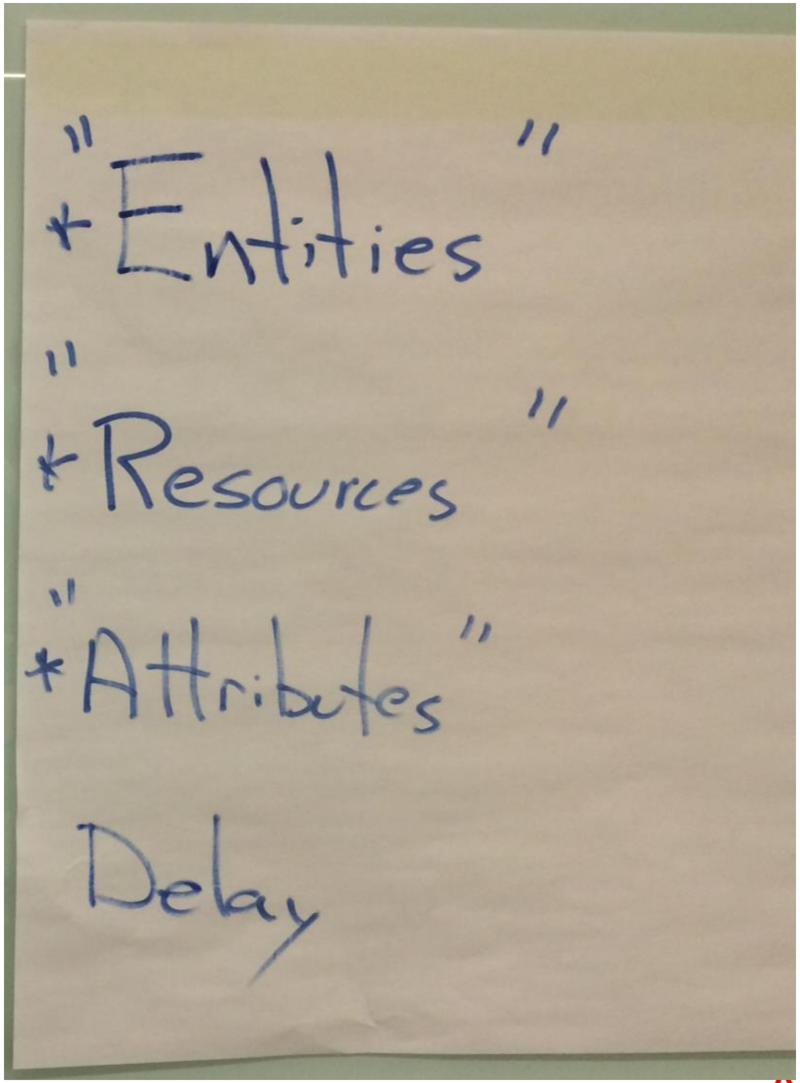
How is simulation used?

1. Investigate “what if” questions (change tests)
2. Identify improvement opportunities
3. Identify critical process parameters
4. Optimize processes
5. Initial off-line starting conditions to fine-tune in practice
6. Demonstrate general process design concepts
7. Convince others of idea(s)

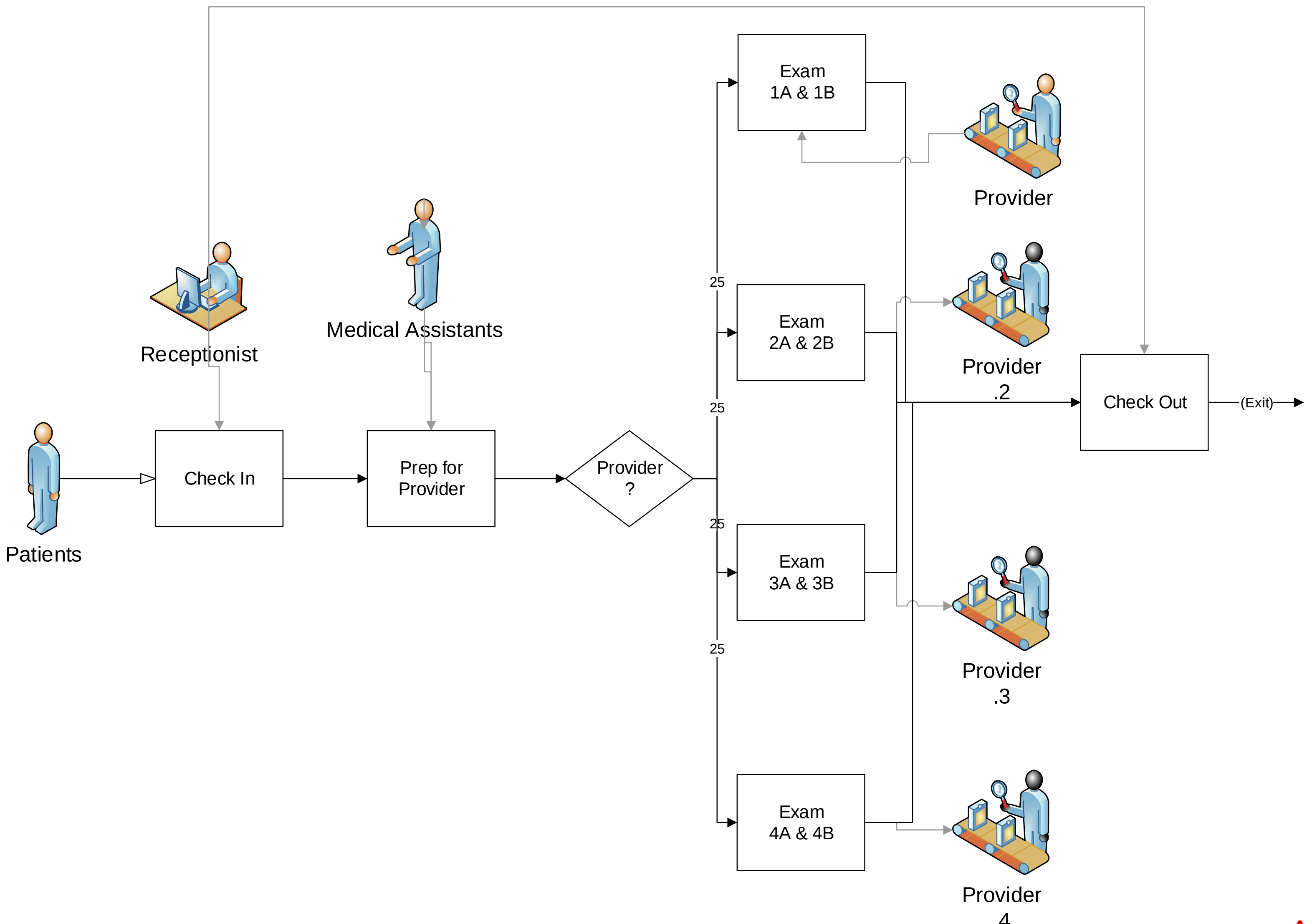
Basic terminology

- Entities – things that flow through the model
  - Patients, records, info, etc
- Resources – things that entities occupy (‘seize’)
  - Patients, records, info, etc
- Attributes – features of entities
  - Age, gender, acuity, # prior readmits, new/established,…

Queue, seize, delay, release

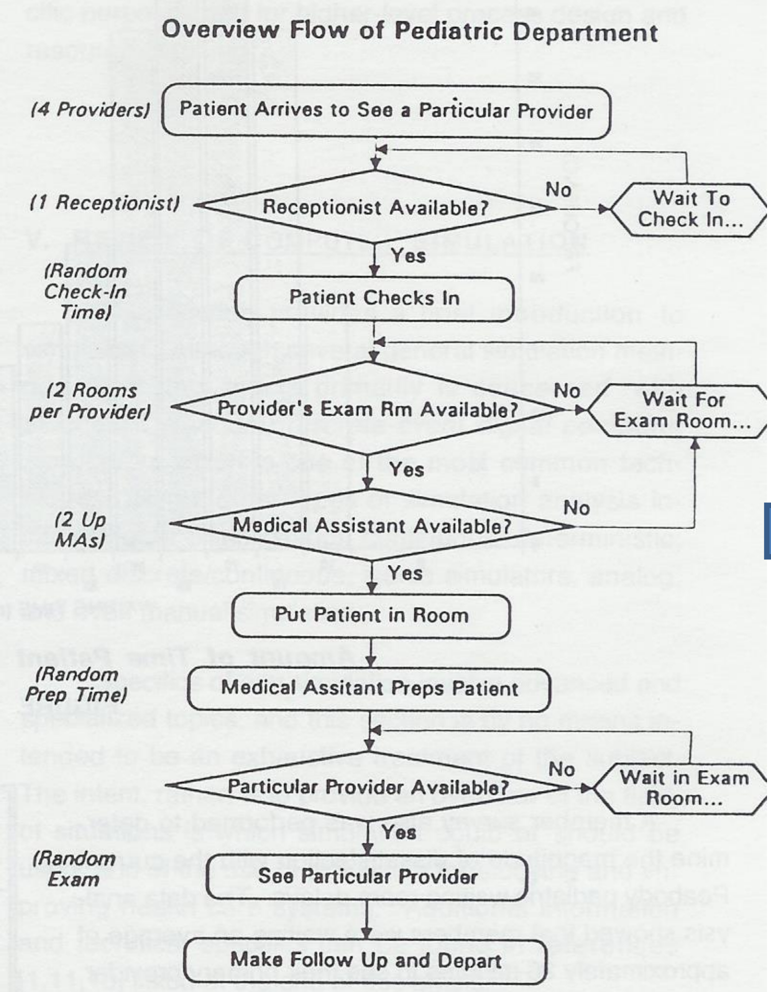


A simple patient flow model



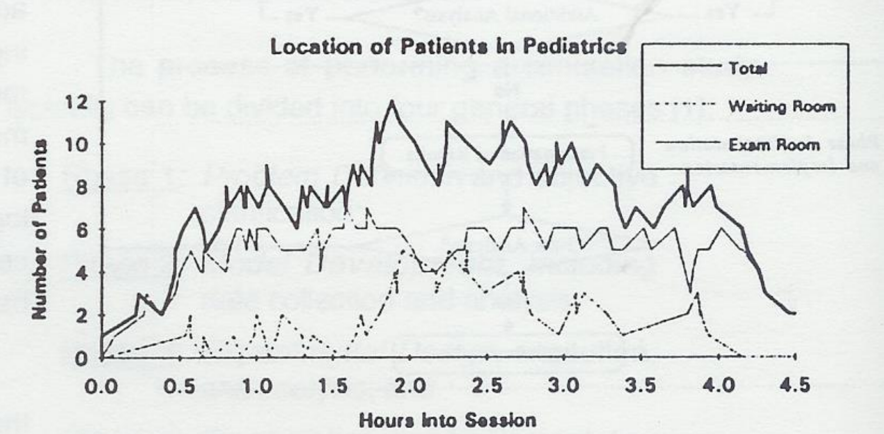
Example: Outpatient clinic flow

Process Logic

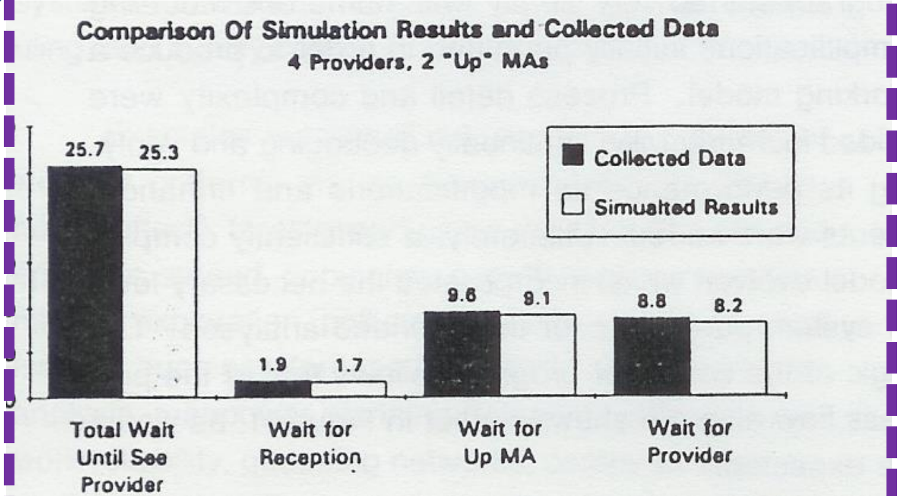


Patient Flow Through a Pediatric Department

Analysis Results & Accuracy



Location of Patients in Pediatrics

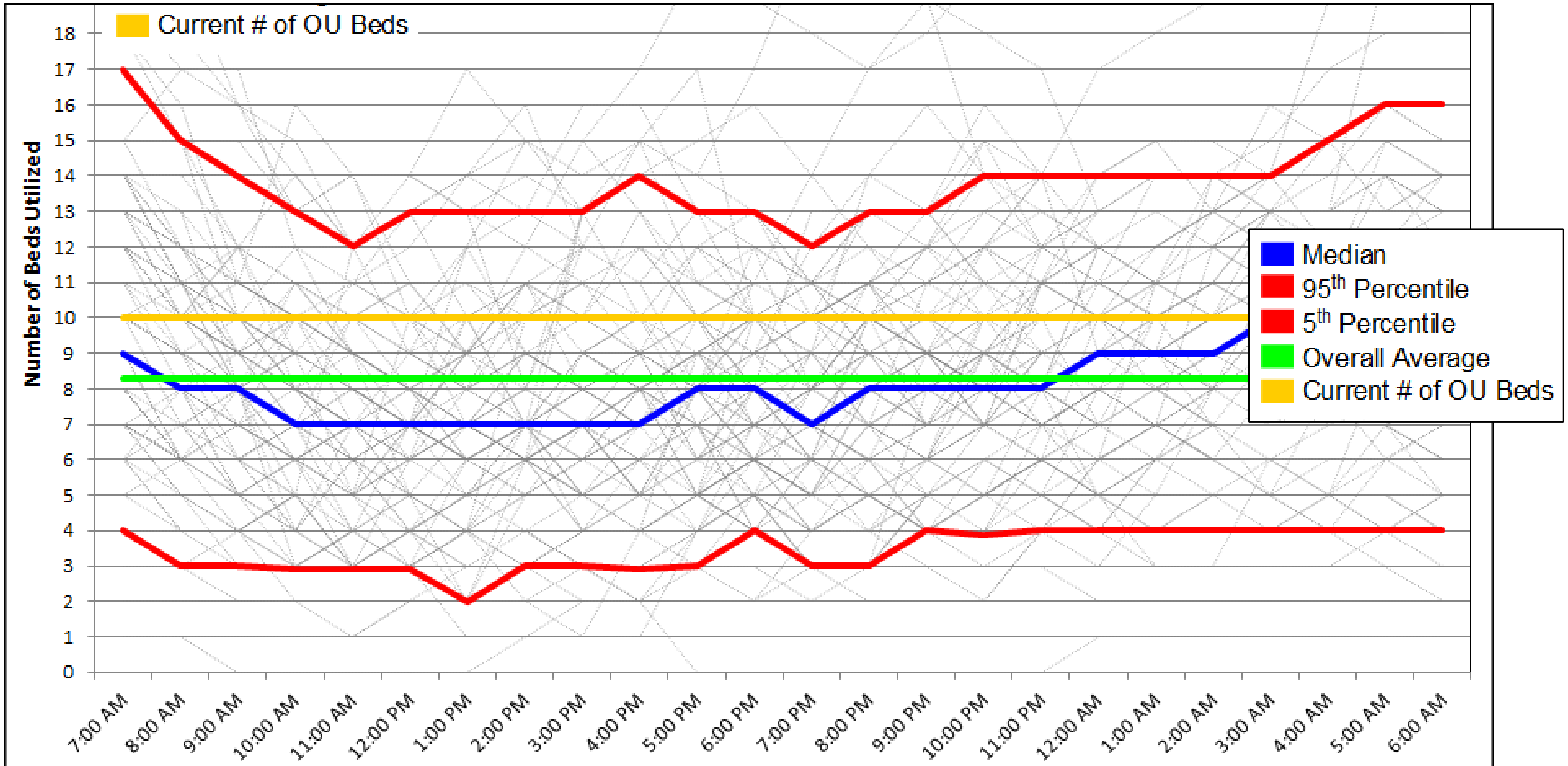


Benneyan, 1997, An introduction to using computer simulation in healthcare, *Jrl Society Health Systems*, 5(3):1-15.

Importance of replications

Observation Unit Capacity Model

(every day is different…)

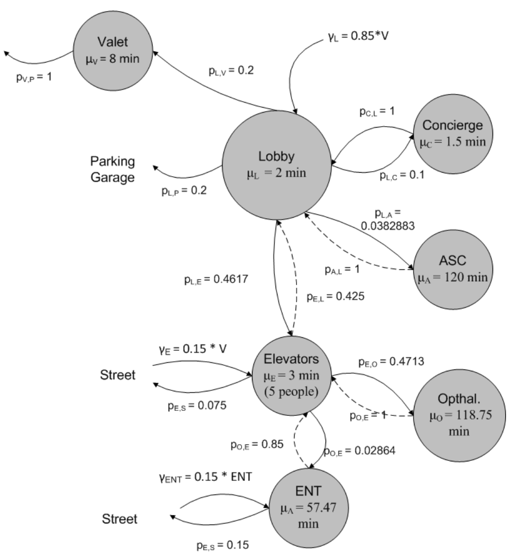


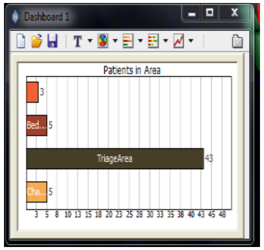
(Click here to run)

Macro system example

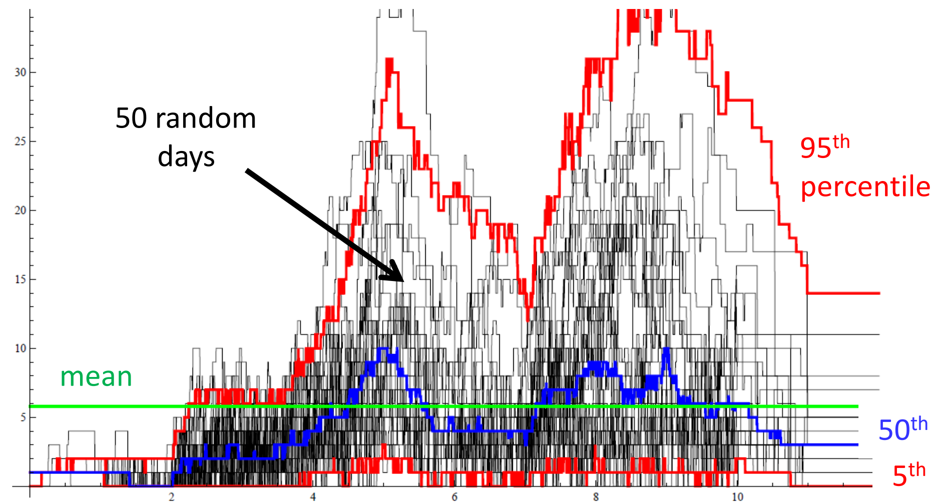
- New facility master space planning
- Queuing flow simulation

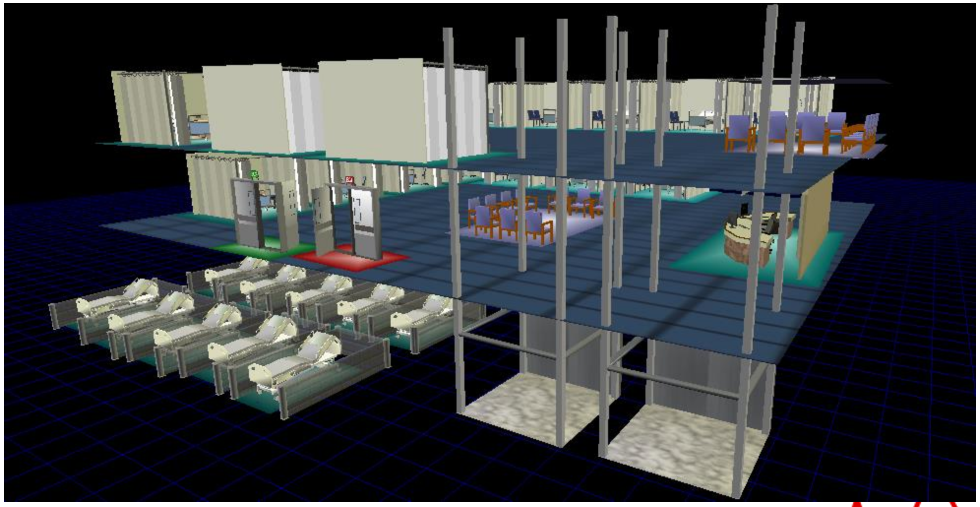
Massachusetts Eye and Ear
experience. life.





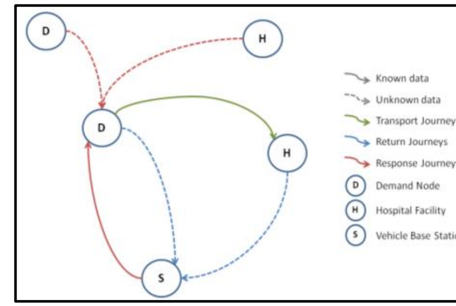
Number people in Lobby by time of day





Regional EMS example

- Ambulance location and routing
- Maximize survival probabilities

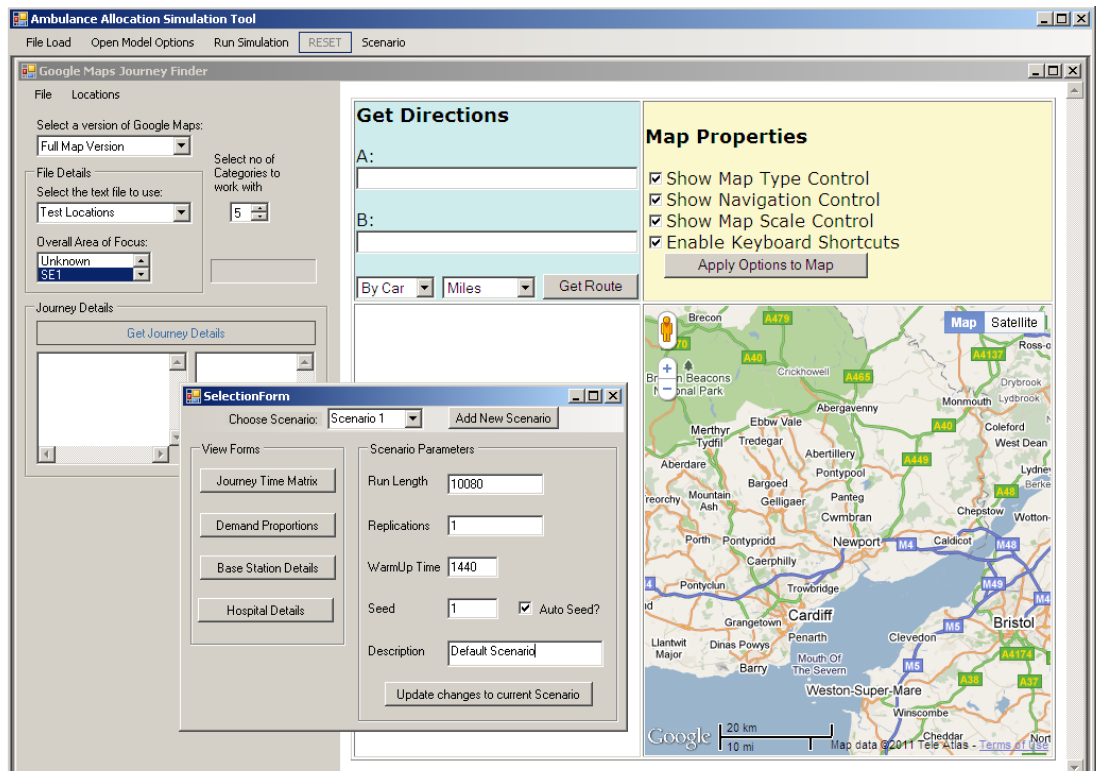


GWENT NEWS

Welsh ambulance review urges end to 8-minute 999 target

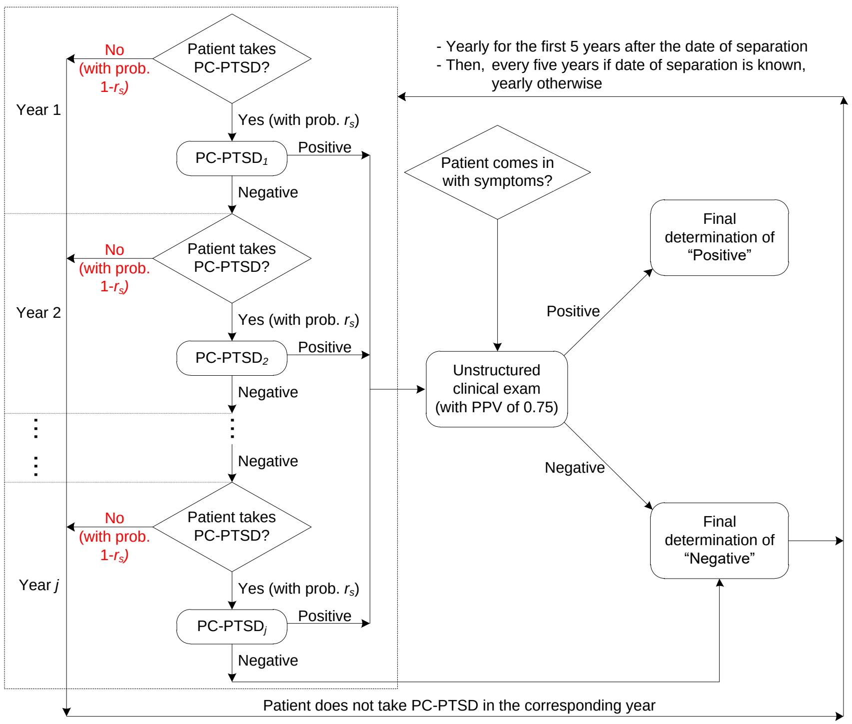
By Andy Rutherford - Health correspondent 5:46pm Monday 29th April 2013 in Gwent news

Welsh ambulance review urges end to 8-minute 999 target



Medical decision making example

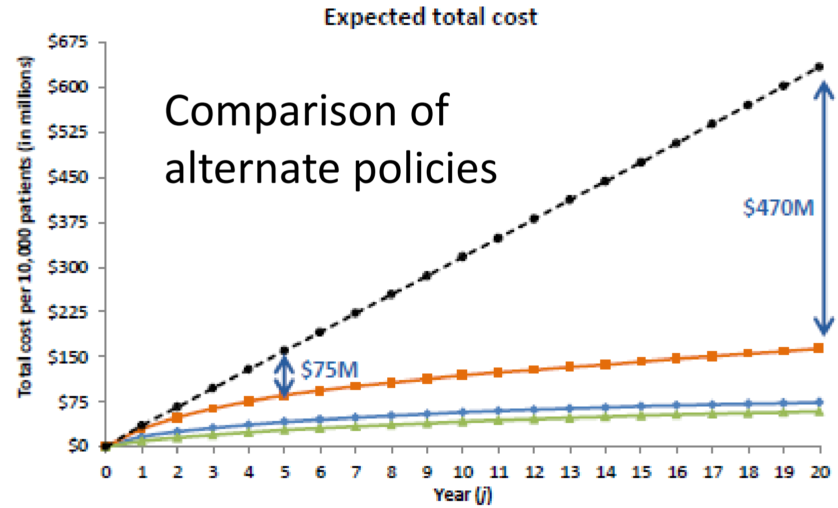
Screening (PTSD, Melanoma, others)

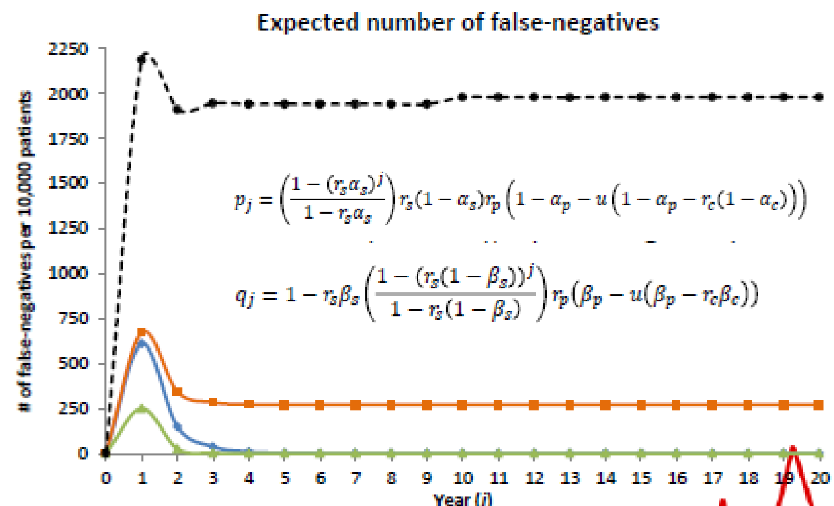


Questions: Accuracy, cost, workload?

Benneyan, Kaminsky, Statistical and economic models for analysis and optimal design of screening policies for cervical cancer, *Ann Ops Res 67(1): 235-285* 1996

Example Results





Example

Bird flu simulation (click here)

Health policy examples

Organ Transplant Multiple Offer Policies

- Simultaneous offers to improve utilization & time till transplant
- Model-informed policy debate

American Journal of Transplantation 2010; 10 (Part 2): 1081–1089
Wiley Periodicals Inc.

DonorNet and the Potential Effects on Organ Utilization

D. A. Gerber[a,*], C. J. Arrington[b,c], S. E. Taranto[d], T. Baker[d] and R. S. Sung[b,e]

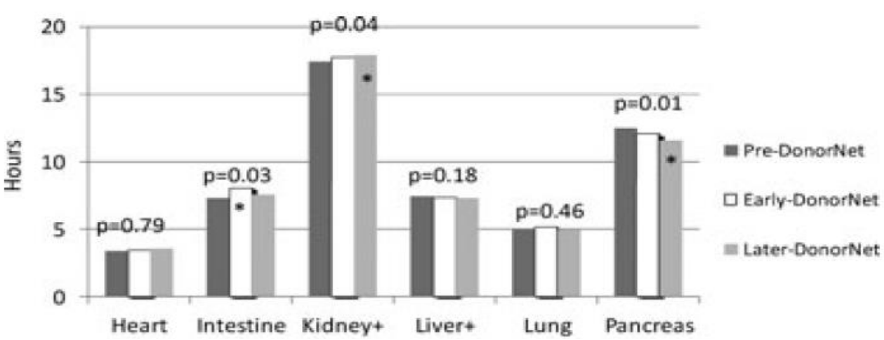
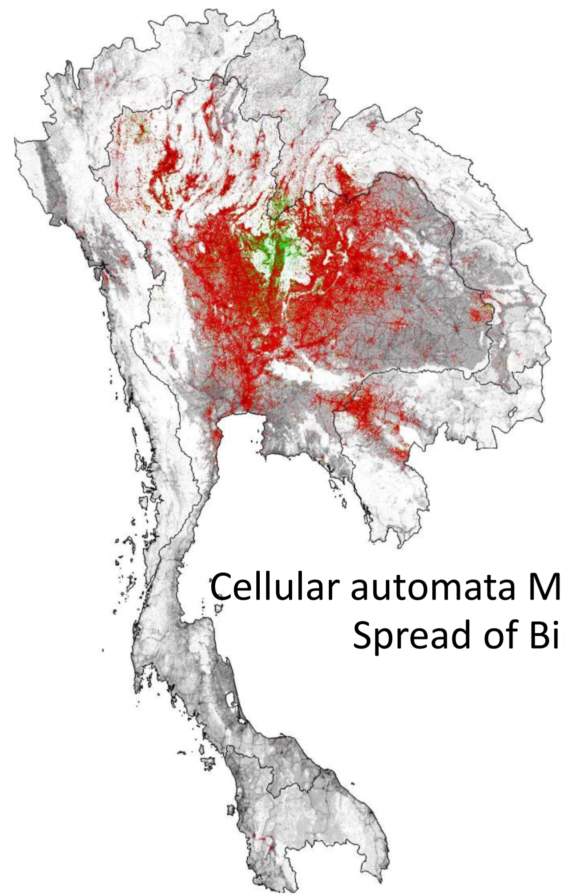


Figure 1: Mean ischemic time for transplanted organs, by organ and time period.

Spread of Epidemics (or improvements)

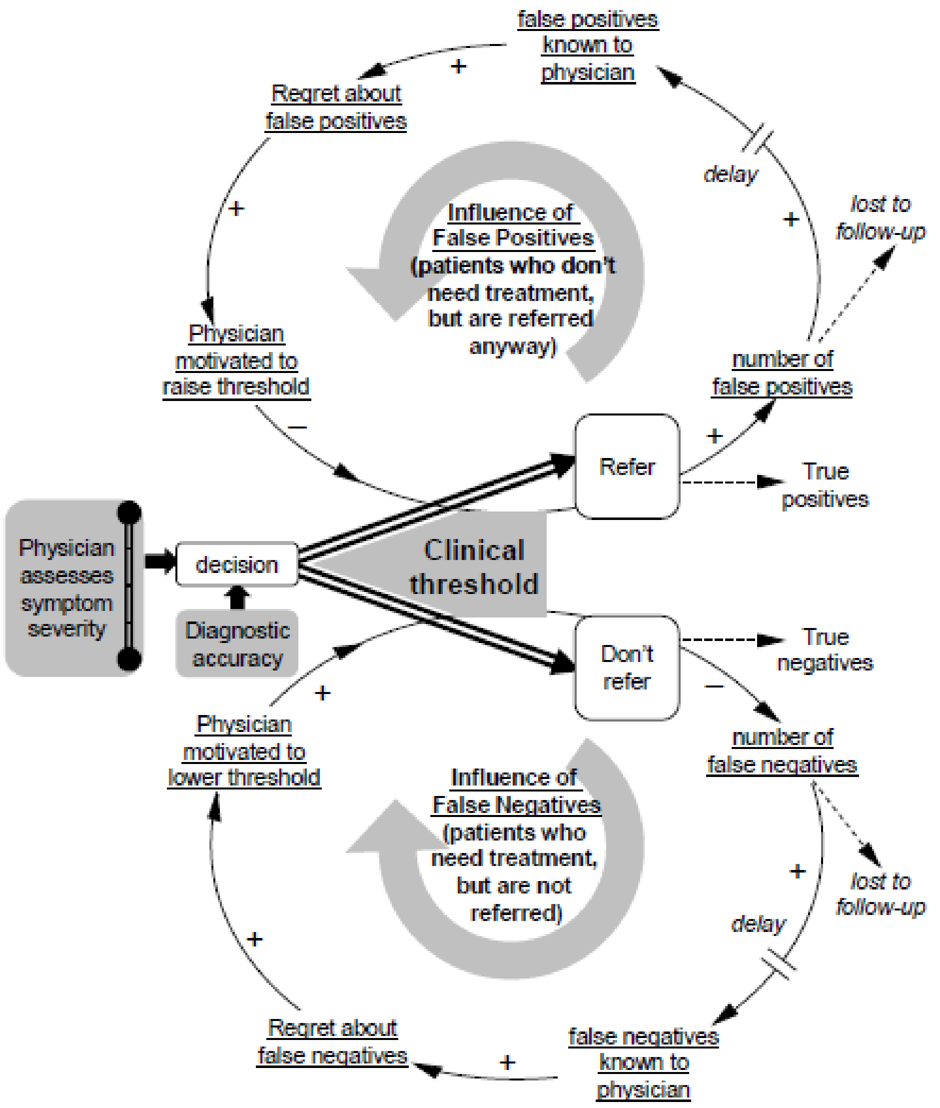


Cellular automata Monte Carlo Spread of Bird Flu

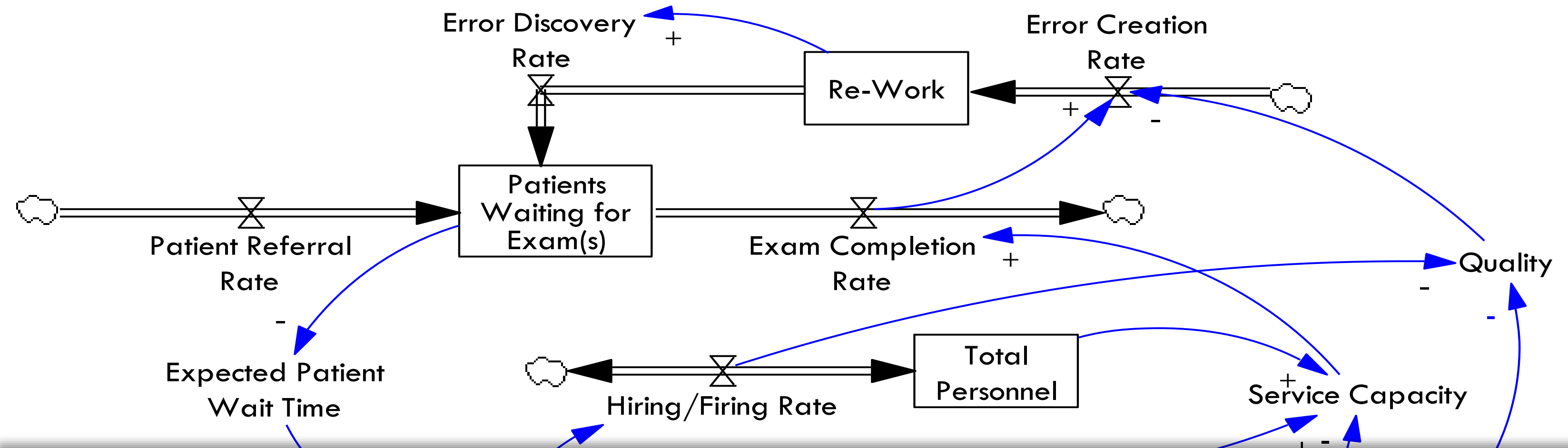
System dynamics example

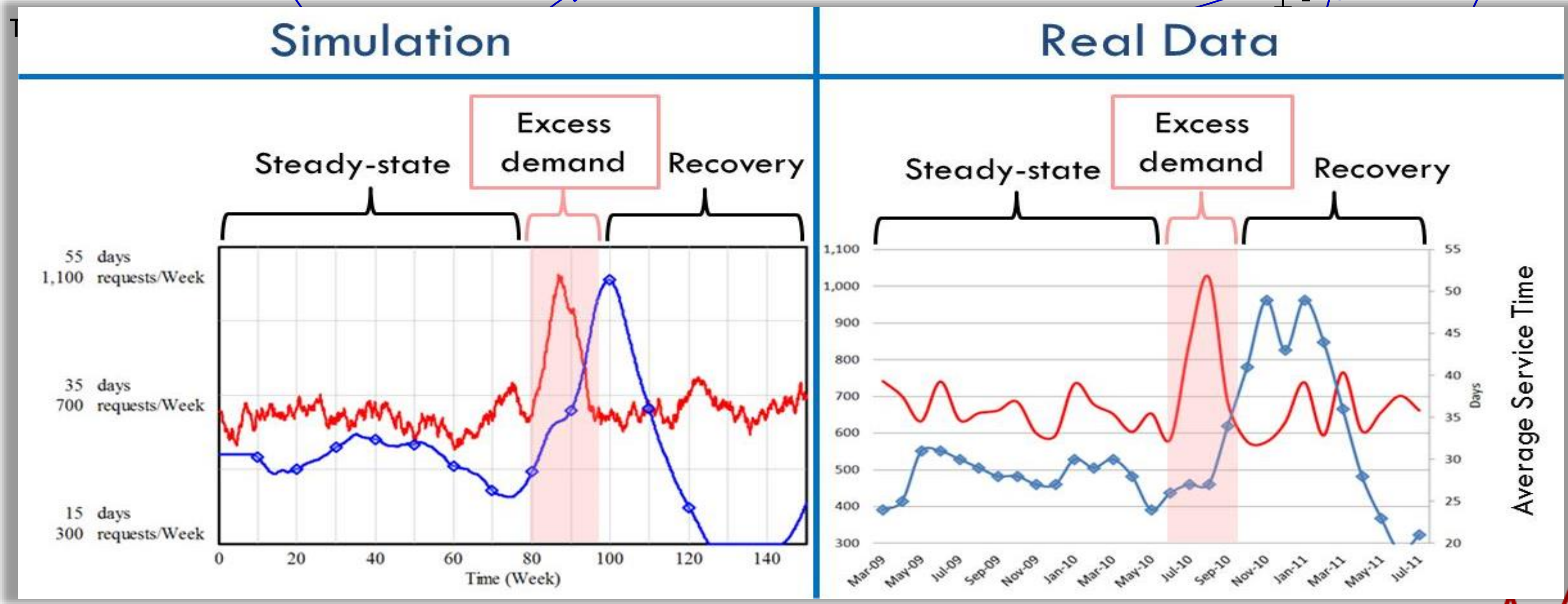
- Typically macro level or policy analysis
- Concepts of 'flows', 'stocks', 'rates', feedback loops
- Based in differential equations
- Also very useful thinking exercise

Figure 1. Trade-offs between higher and lower clinical thresholds



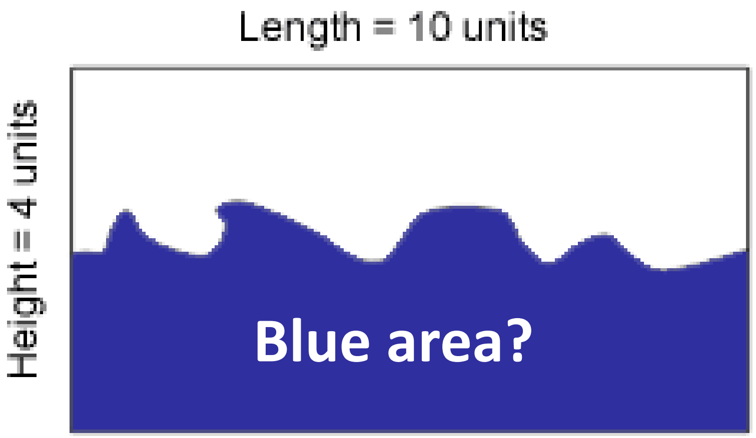
System dynamics example

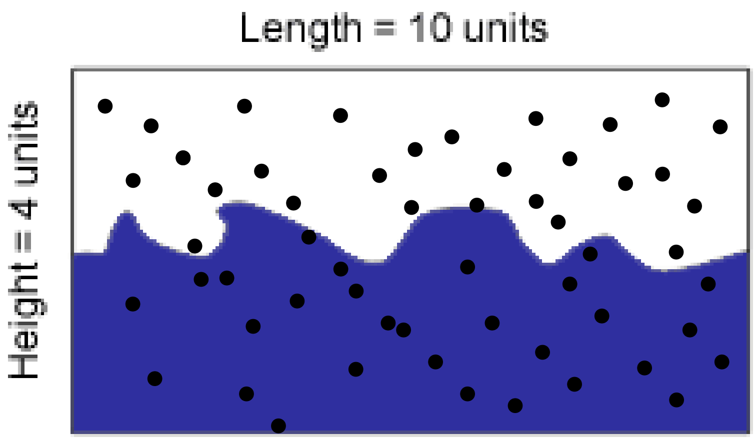




Monte Carlo Integration

- General logic (proportion area method)
- Examples
- Other functions, triangular, others.
- 2^{nd} method for Pi
- 2nd method (expected value method)

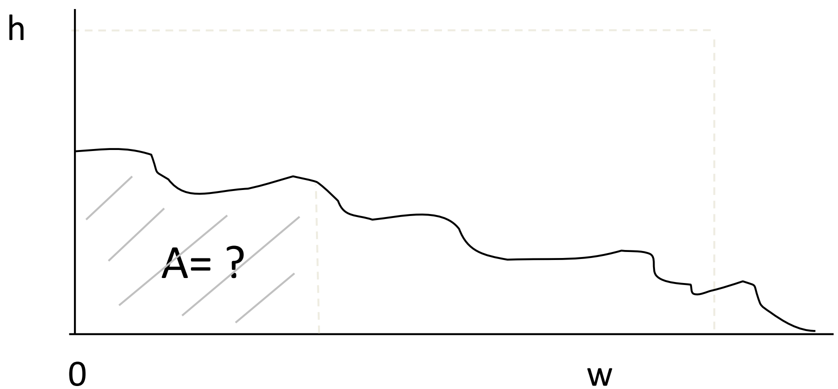


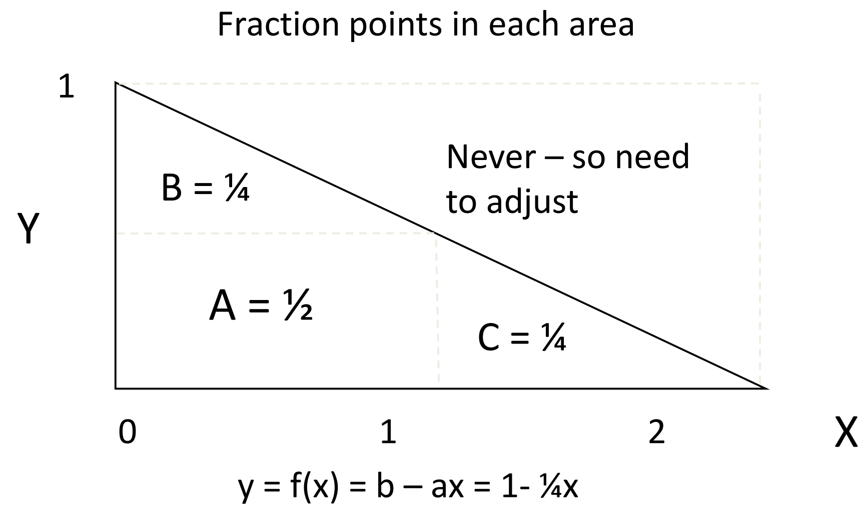


$$\text{Fraction of Area} = \frac{\text{Number points in blue area}}{\text{Total number of points}}$$

MC Integration cont'd

Examples



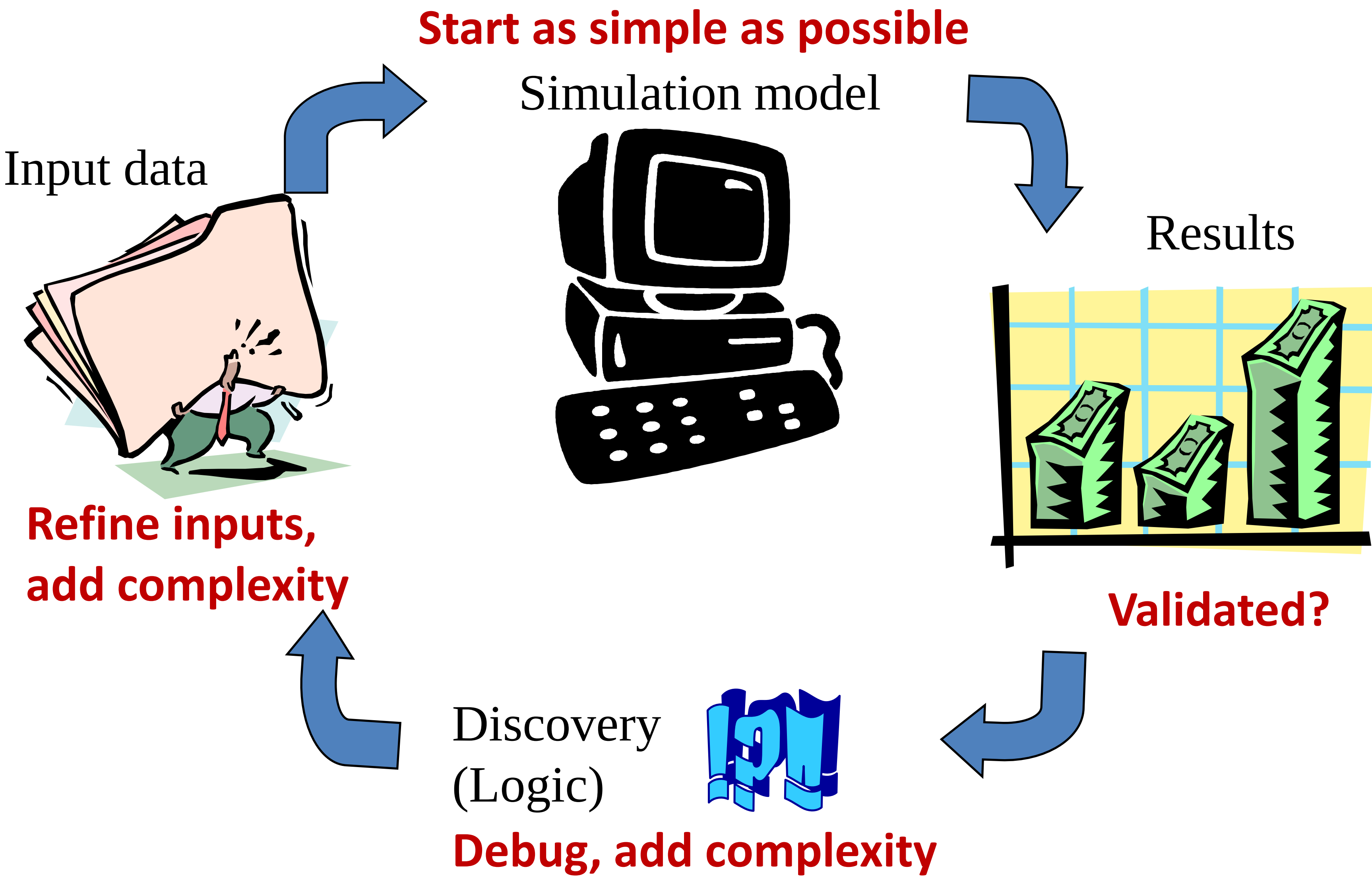


$$\underline{\text{Since}}:\ \text{Fraction of total area under curve} = \frac{\text{Area under curve}}{\text{Total area of rectangle}}$$

$$\underline{\text{Then}}:\ \text{Area under curve} = \text{Fraction under curve} * \text{Area of rectangle}$$

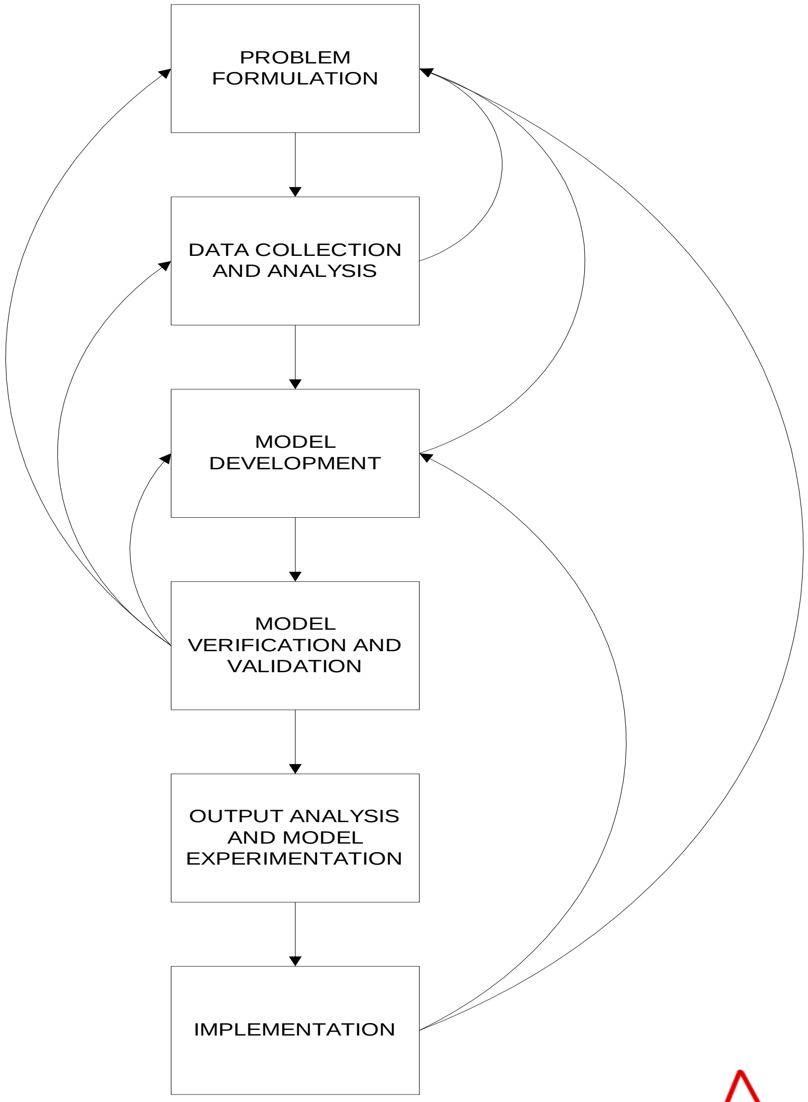
Conducting simulation studies

Building simulations = iterative process

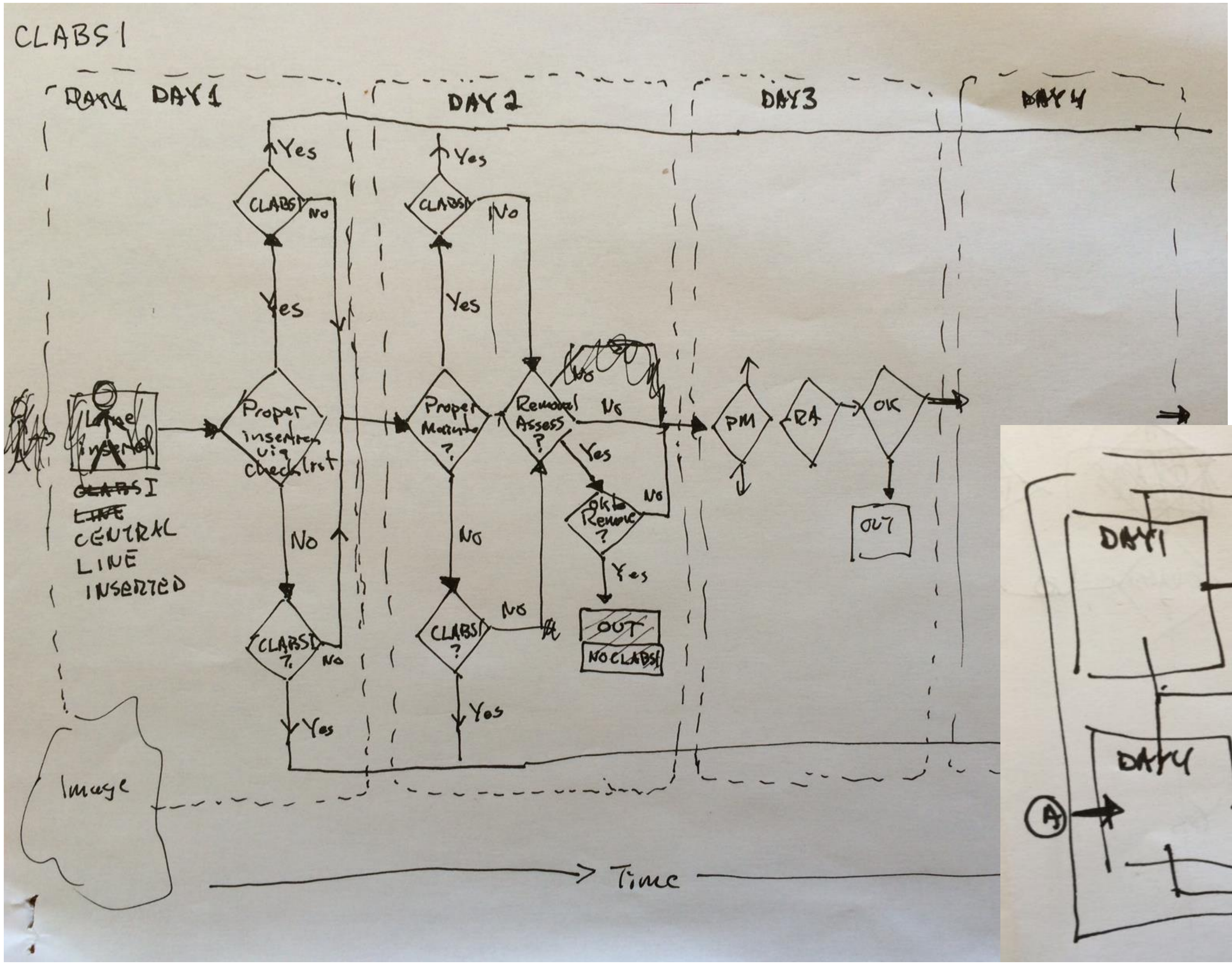


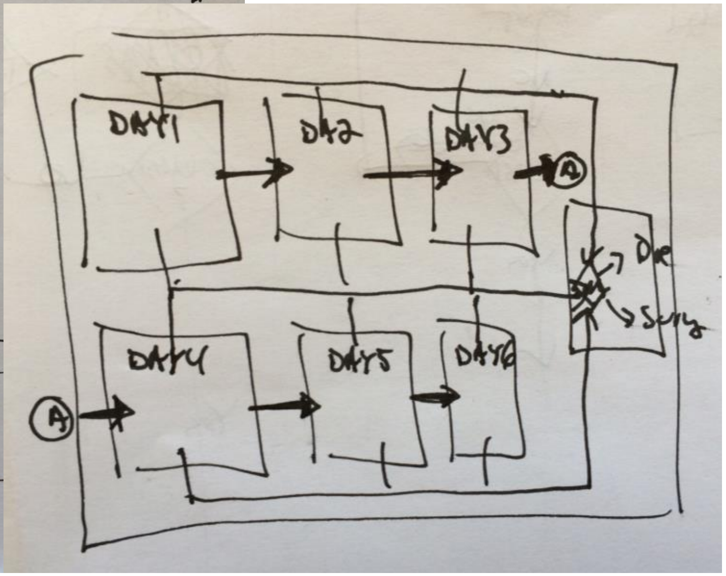
Lifecycle

1. Problem definition
2. Model development
3. Verify & validate model is correct and produces reasonable results
4. ‘Pilot runs’ to obtain preliminary results
5. Experiments and results (‘production runs’)
6. Implement, test *in vivo*



Model development process (clabsi)



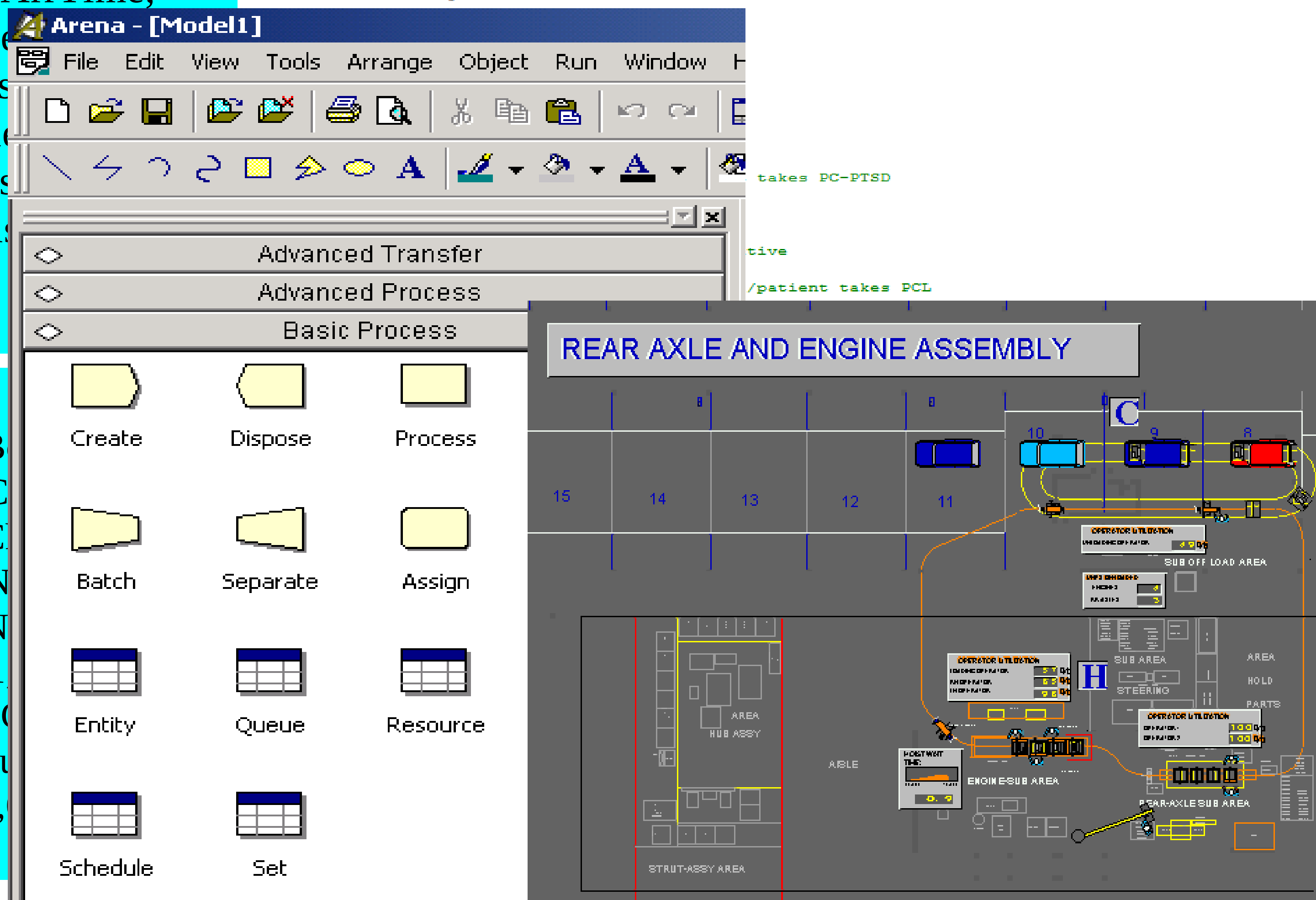


How is logic represented

(what does/did other software look like)

```
BEGIN;
CREATE:         IntArrTime;
QUEUE,          Che
SEIZE:          Cas
DELAY:          Che
RELEASE:        Cas
COUNT:          Cus
DISPOSE;
END;
```

```
BEGIN;
PROJECT,          B
RESOURCES:        C
QUEUES:           C
DSTATS:           N
                  N
EXPRESSIONS:      1
–                 2,
COUNTERS:         Cu
REPLICATE,        2,
END;
```

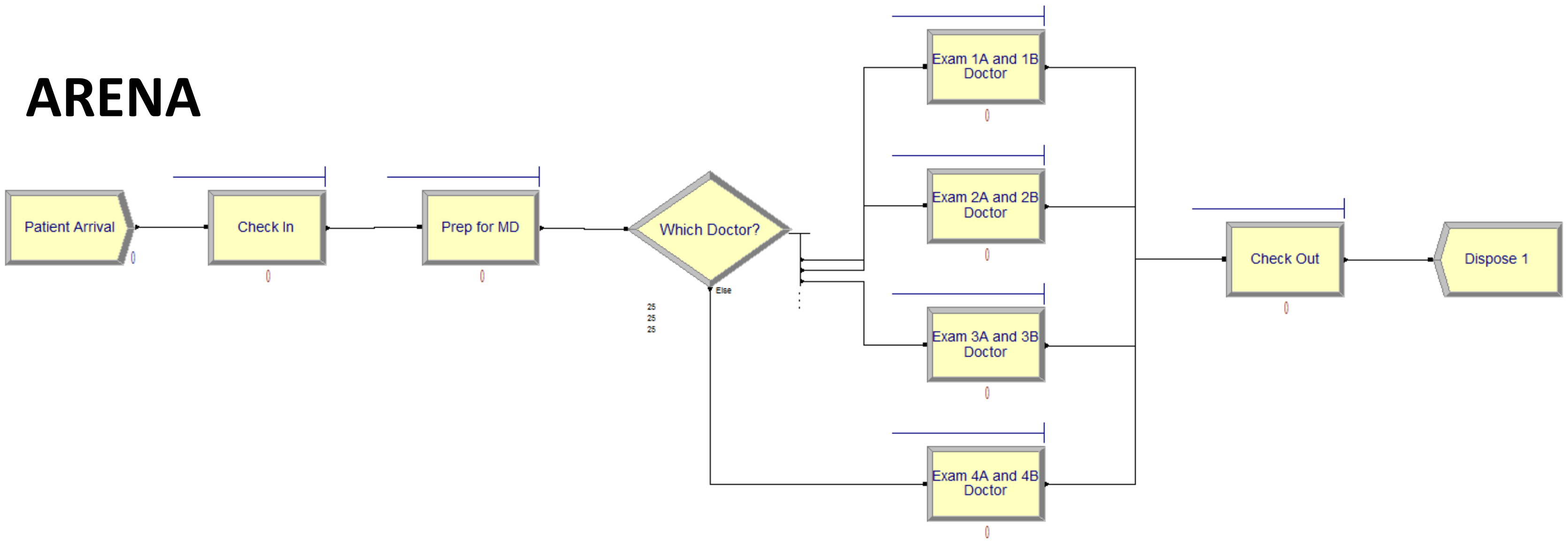


Some common software

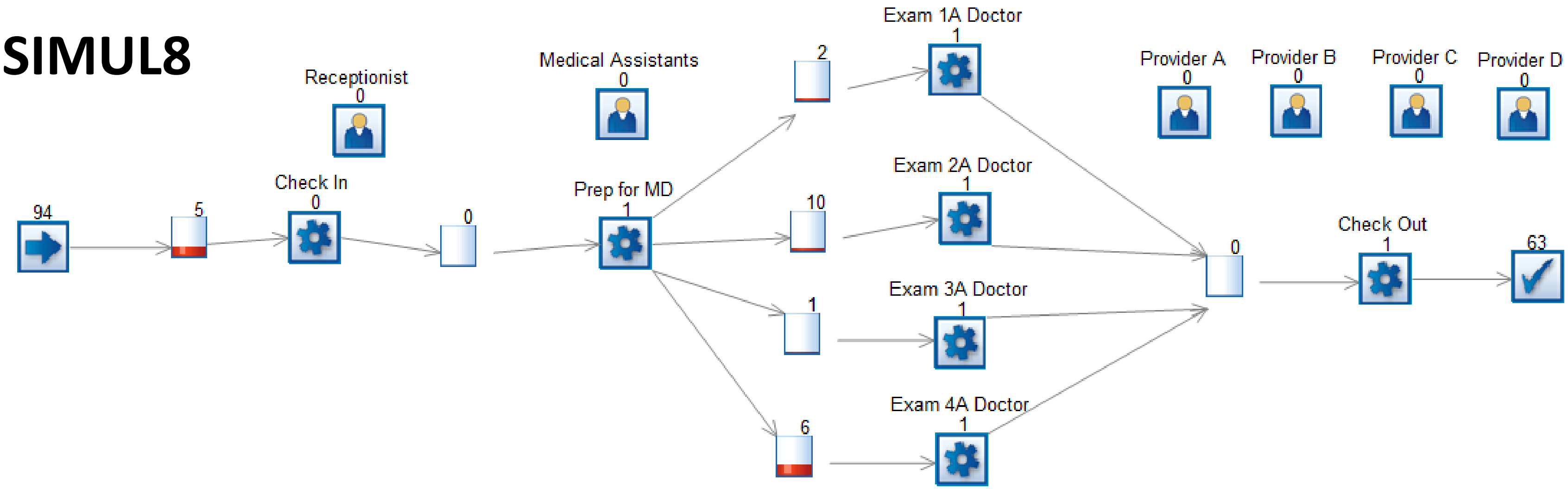
1. ARENA
2. ProModel, MedModel
3. FlexSim
4. Process Simulator
5. Simul8
6. Extend
7. AnyLogic

Other software – same model

ARENA



SIMUL8



Examples of output

ARENA

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Check In	1.8398	0.02	1.7291	1.9331	1.0192	2.9552
Check Out	3.5923	0.07	3.2466	3.8926	1.0710	6.8977
Exam 1A and 1B Doctor	19.1350	1.92	13.6526	32.5950	0.00	114.77
Exam 2A and 2B Doctor	44.9945	0.23	43.7401	45.9167	40.2320	49.7469
Exam 3A and 3B Doctor	20.9338	1.68	14.6840	31.4969	0.00	80.8902
Exam 4A and 4B Doctor	24.9455	1.15	18.4053	30.5419	0.00	60.3987
Prep for MD	7.0192	0.16	6.2871	7.8066	0.00	19.4944

Wait Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Check In	10.0603	1.84	3.9458	20.2454	0.00	51.3141
Check Out	10.2126	2.01	3.1379	22.5383	0.00	55.0713
Exam 1A and 1B Doctor	38.3450	13.52	6.4692	123.12	0.00	251.20
Exam 2A and 2B Doctor	96.6793	10.27	38.8139	156.74	0.00	276.30
Exam 3A and 3B Doctor	38.6825	11.12	9.2126	89.7540	0.00	192.72
Exam 4A and 4B Doctor	40.7290	10.45	4.2204	105.60	0.00	157.70
Prep for MD	7.0415	1.43	2.5603	14.6382	0.00	43.8796

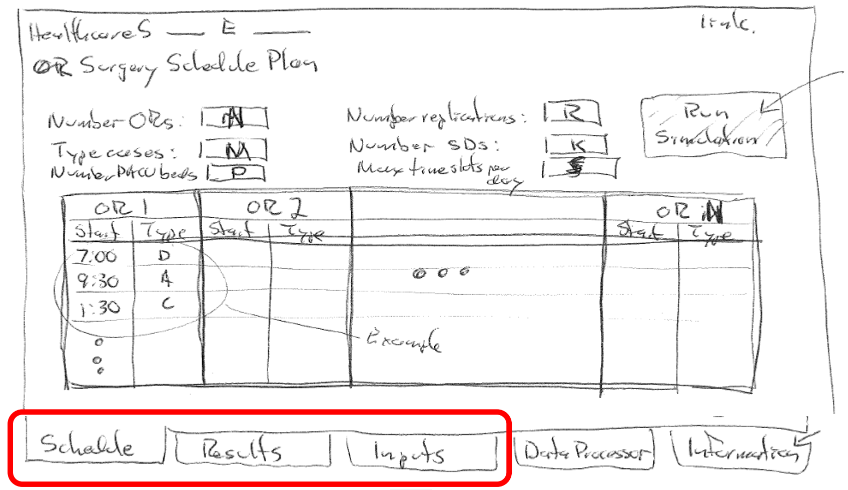
SIMUL8

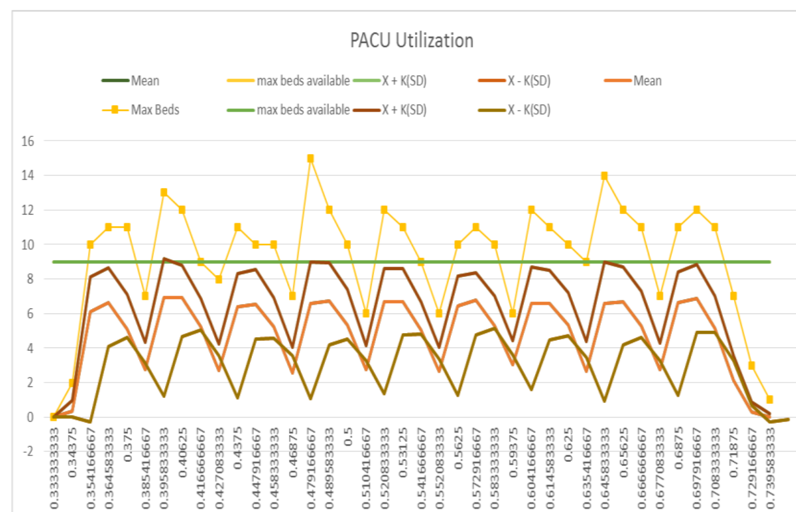
	Minimum Queue Size	Average Queue Size	Maximum Queue Size	Minimum Queuing Time	Minimum (Non-zero) Queuing Time	Average Queuing Time	Average (Non-zero) Queuing Time	Maximum Queuing Time	Number of Non-zero Queuing Times	% Queued Less Than Time Limit
Queue for Check In	0	1.824	6	0	0.414	9.597	10.812	22.54	79	52.809
Queue for Prep for MD	0	0.864	5	0	0.042	4.877	6.603	19.409	65	77.273
Queue for Exam 1A Doctor	0	0.356	3	0	0.263	6.224	14.937	37.668	10	75
Queue for Exam 2A Doctor	0	6.764	11	0	19.772	160.431	176.474	313.482	10	9.091
Queue for Exam 3A Doctor	0	0.646	3	0	6.981	19.992	29.988	55.439	10	46.667
Queue for Exam 4A Doctor	0	2.368	6	0	15.034	45.539	48.218	122.982	17	5.556
Queue for Check Out	0	1.021	6	0	0.275	8.193	9.199	26.179	57	56.25

Show output report

Excel model (OR-to-PACU flow)

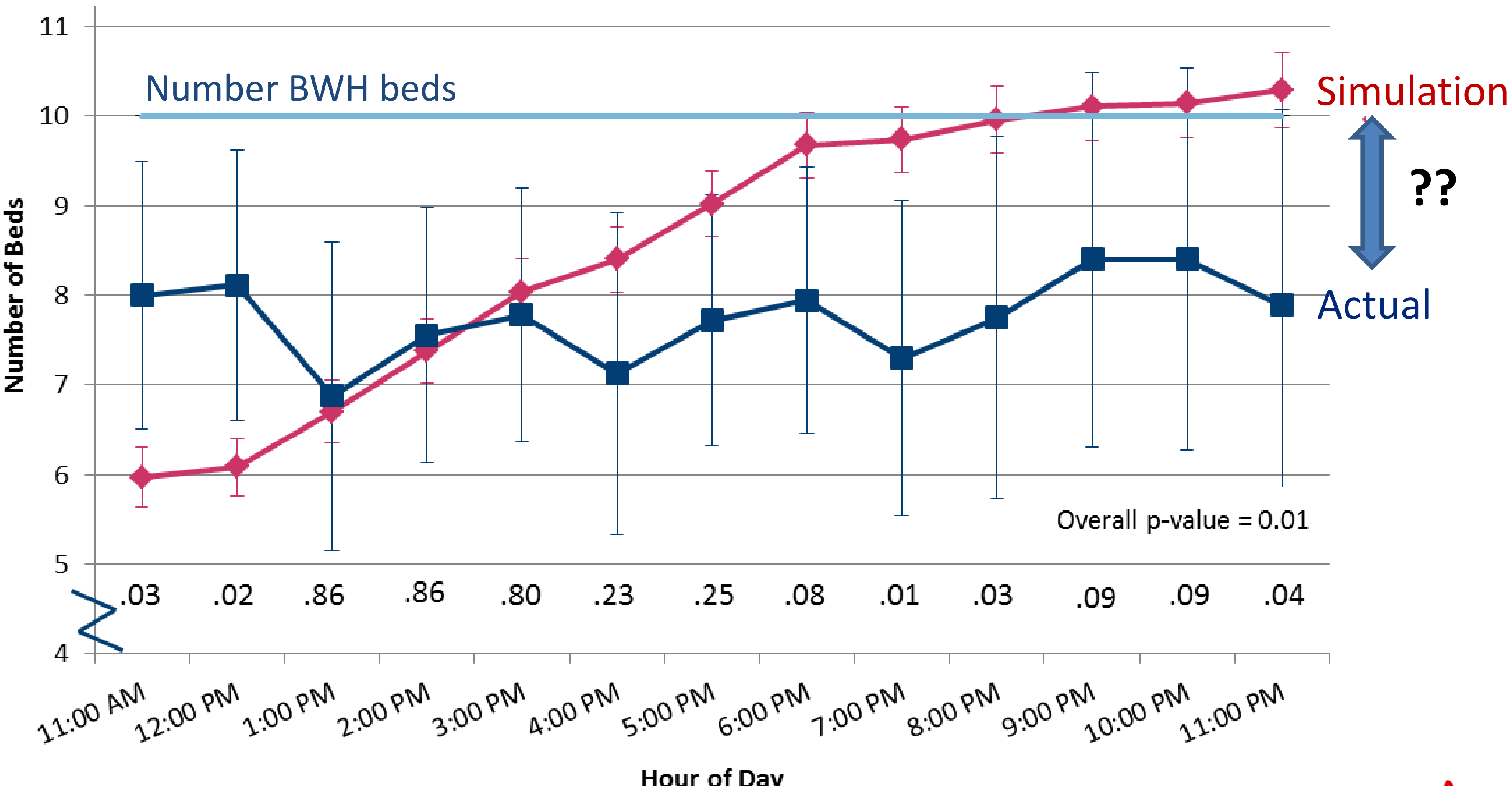
- Excel Monte Carlo file
- Scheduled upstream work (elective surgery, chemo labs)
- Partial or full flow to down stream process (eg, PACU recovery, infusion)
- Process variations causes log jams, delayed starts, etc
- Play around with schedule changes to avoid potential problems



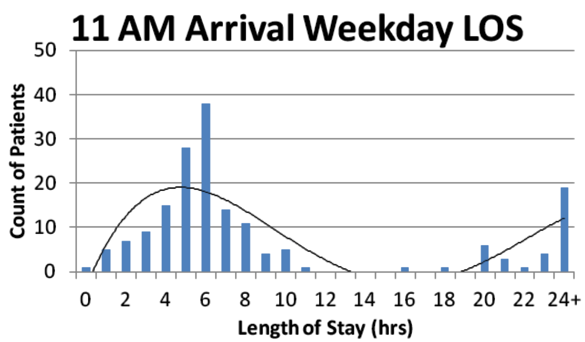


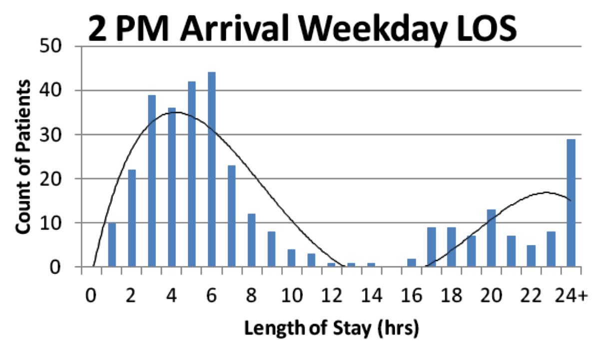
Validation example

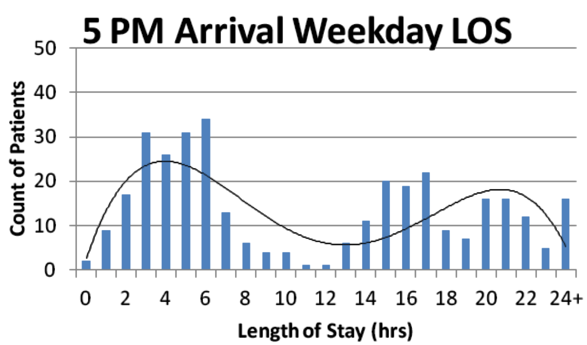
Iterative process – Obs Unit bed demand

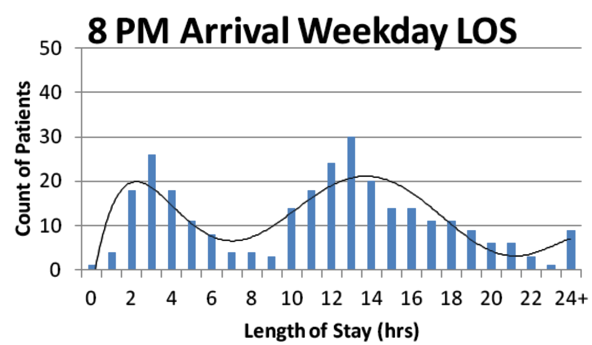


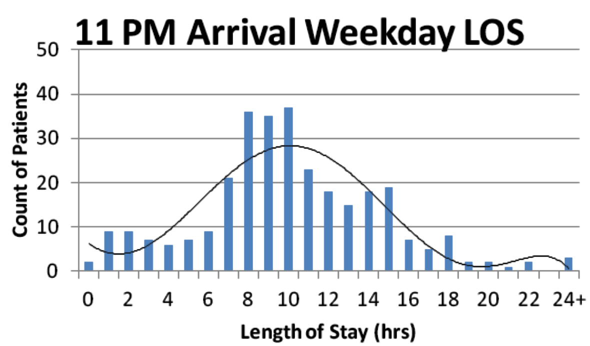
LOS distributions by arrival time



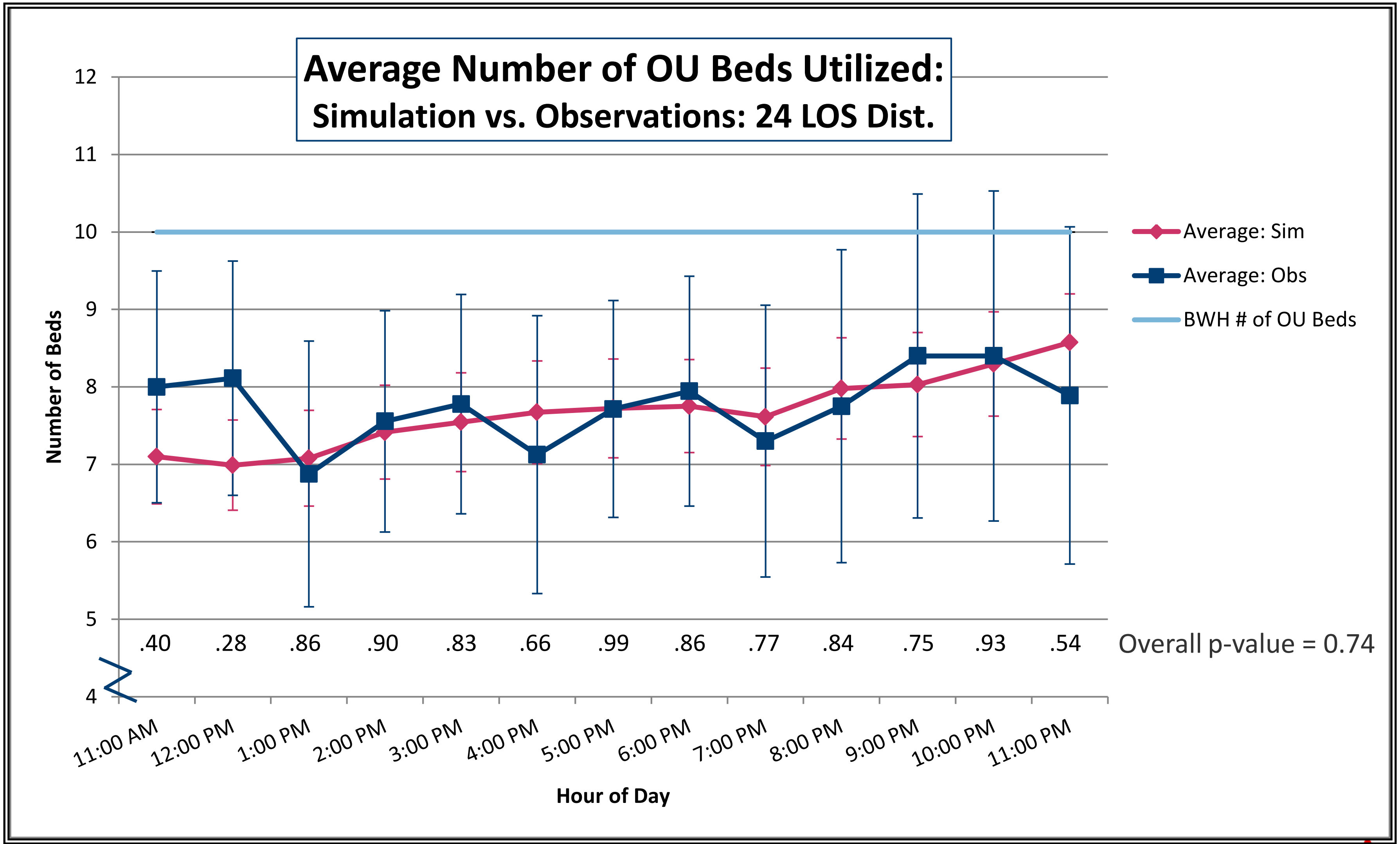








After adjusting for non-constant arrival patterns



“meta-model”

Regression concept:

$$\underset{\uparrow \atop \text{Performance measure of interest}}{Y} = B_0 + \underbrace{B_1X_1 + B_2X_2 + \ldots}_{\text{Process decision variables (“main effects”)}} + \underbrace{B_{1,2}X_1X_2 + \ldots}_{\text{2-way interaction effects}} + \underbrace{B_{1,2,3}X_1X_2X_3}_{\text{3-way interaction effect}}$$

- Run model under different settings
- Terms with largest coefficients have largest impact on performance measure

Our pediatric case study

Run	MAs	Rooms	MDs	Waits	MD utilization	Cost
1	1	2	1			
2	1	2	3			
3	1	4	1			
4	1	4	3			
5	3	2	1			
6	3	2	3			
7	3	4	1			
8	3	4	3			
9	2	3	2			

Fall ‘13 example – regression results

Healthcare Simulation DOE/Optimization example

		results	Bounds			Relative		
"Decision variables"			Lower	Upper		Cost units		
# MDs =	X1 =	8	2	8		2		
Rooms =	X2 =	7	1	8		1		Cost
Nurses =	X3 =	2	2	8		1		Upper bound
						25	<	25

Performance measures			
mean	=	44.495	sd
variance	=	60.183	7.76

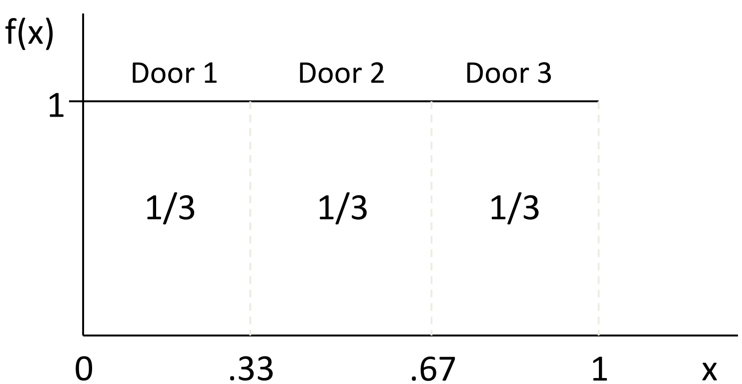
								MDs
					MDs	MDs	Rooms	Rooms
		MDs	Rooms	Nurses	Room	Nurses	Nurses	Nurses
Regression coefficients								
	intercept	X1	X2	X3	X1X2	X1X3	X2X3	X1X2X3
mean	69.88	-3.344	-1.185	-1.65	0.043	0.426	-0.229	0.062
Variance	603.07	-51.616	-22.959	-36.959	-1.168	4.274	-0.368	0.954

Generating Events

- How simulate a coin toss, dealt card, chosen door, or baseball "at-bat"?

Example 1: Pick a Door

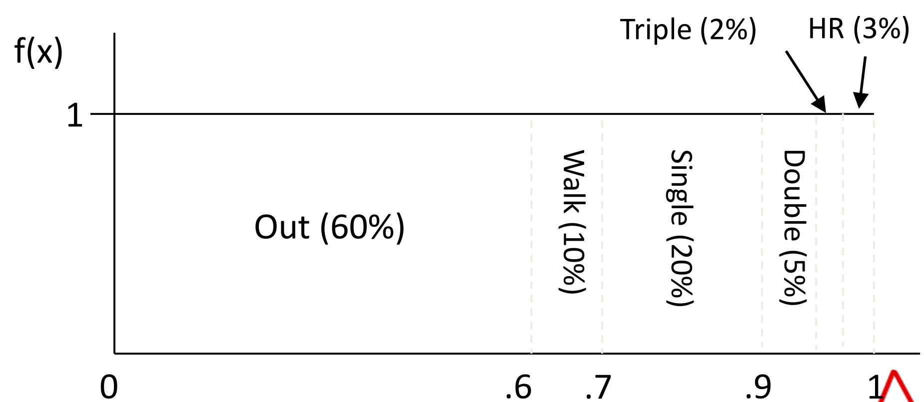
IF U < .33, Door==1
ELSEIF U < .67, Door==2
ELSE Door==3



Equally likely… unequally likely?

Example 2: Take a Turn At Bat

IF U < .6, Out
ELSEIF U < .7, Walk
ELSEIF U < .9, Single
ELSEIF U < .95, Double
ELSEIF U < .97, Triple
ELSE, HomeRun



Program development & Typical outline

<u>Program Development</u>

Flow chart

↓

Pseudo-code

↓

Code

↓

Start simple, validate with known results

↓

Build in complexity iteratively

<u>Typical MC Program Structure</u>

Variable declarations

Input prompts

Initializations

Replication loop

  Process logic

  Data collection & counters

Repeat until condition is met

Statistical calculations

Output results

End

Example

Recall "short cut" formula for variance

$$\text{variance} = s^2 = \frac{\Sigma (x - \bar{x})^2}{n-1}$$

Short cut formula

$$s^2 = \frac{\Sigma x^2 - \frac{(\Sigma x)^2}{n}}{n-1}$$

Initialize Total = 0
Initialize TotalSqr = 0
Initialize NumReps = 0
Input Prompt: DesiredReps (preset or get from user)
Do Until NumReps = DesiredReps
:

Program logic… produce 1 value of performance measure X

:
Let NumberReps = NumberReps + 1
Let Total = Total + X
Let TotalSqr = TotalSqr + X^2
Repeat loop

Update & track inside loop

Let Average = Total / NumberReplications
Let Variance = [TotalSqr – NumReps*(Average)^2)]/(NumReps-1)
Compute or look up T for sample of size n
Let HalfWidth = T*Variance^0.5/NumReps
Print results

Outside loop

Wrap up

Remember Einstein's advice