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Systems Engineering Methods for Improving Patient Access to Care

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Summary

- Opportunities for systems engineering methods to improve health care delivery
- Two examples:

  (1) Modeling patient flow through a family medicine clinic

  (2) An optimization based decision support system for scheduling thoracic surgery

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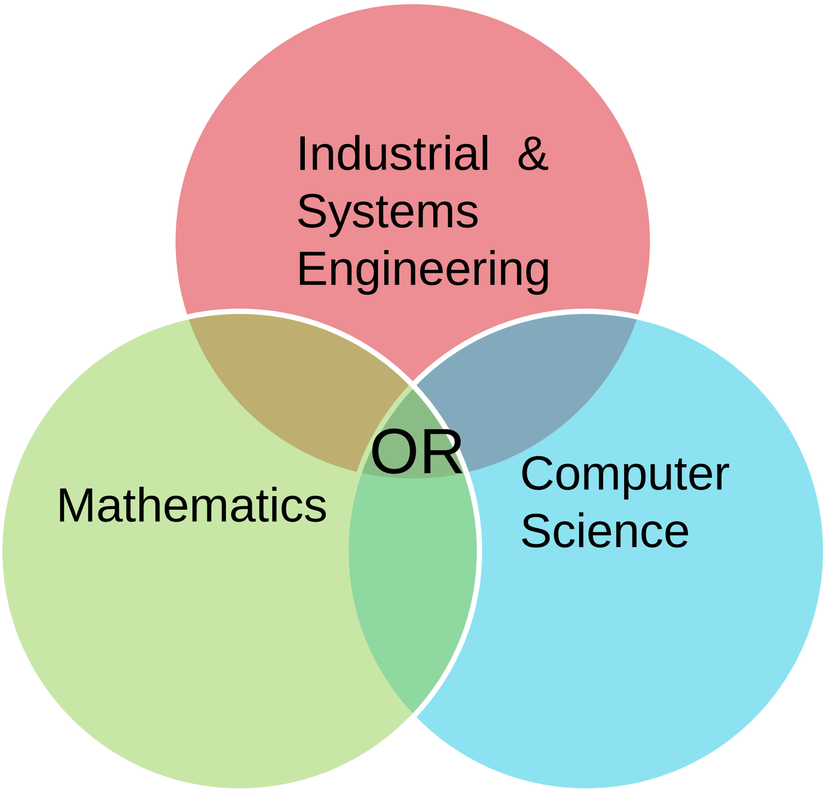
Operations Research



A multidisciplinary field that focuses on analytical methods for optimization of complex systems

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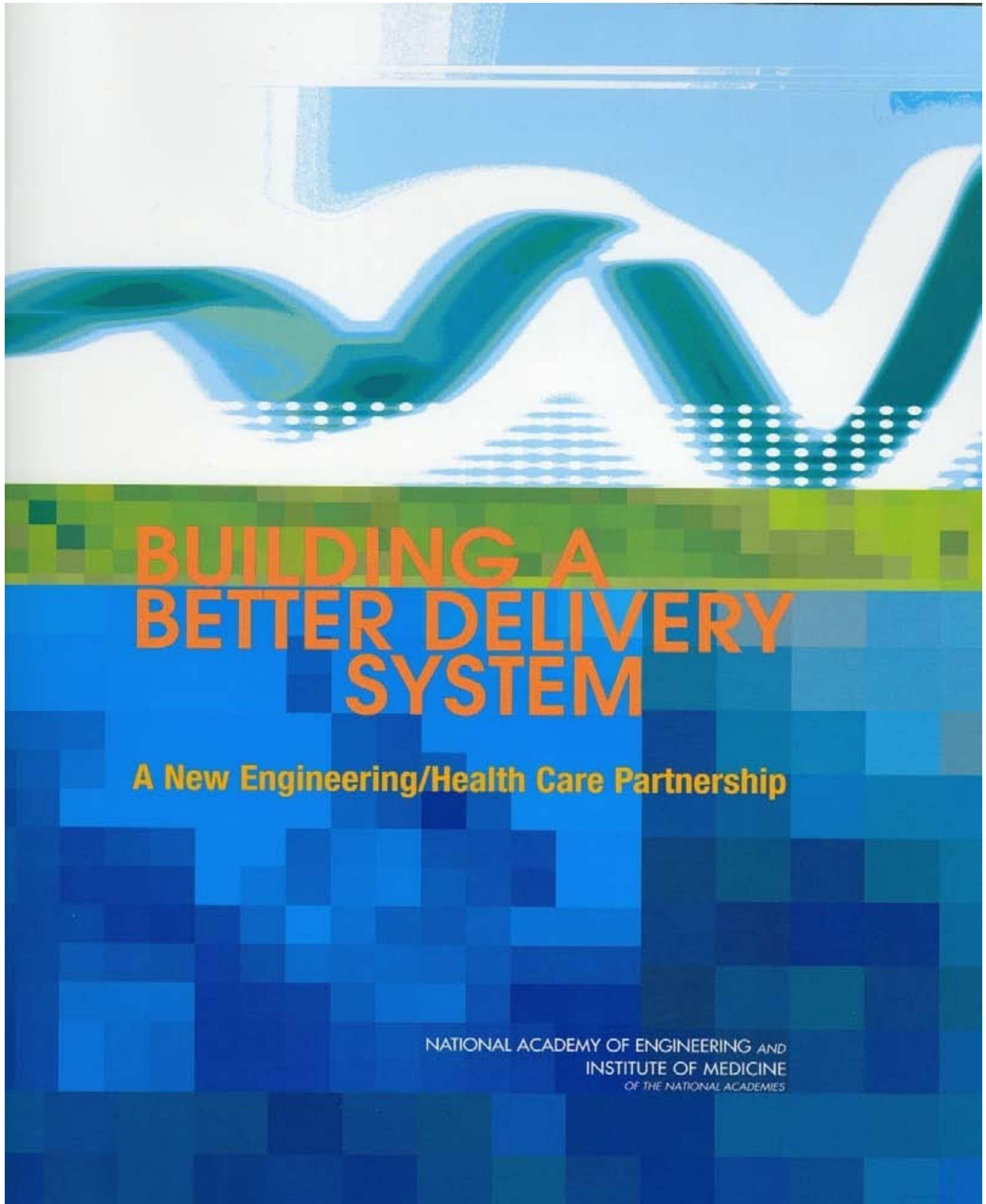

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Analysis of Patient Flow Through UNC Family Medicine Clinic

North Carolina State University
Edward P. Fitts Department of Industrial and Systems Engineering
Senior Design Project

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Sponsored by:
The University of North Carolina
Family Practice

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April 23, 2008

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Project Objectives

- Develop a discrete event simulation model of patient flow through UNC Family Medicine Clinic

- Provide Recommendations to Clinic
  - Identify Bottlenecks
  - Increasing Patient Throughput
  - Decreasing Patient Waiting Time

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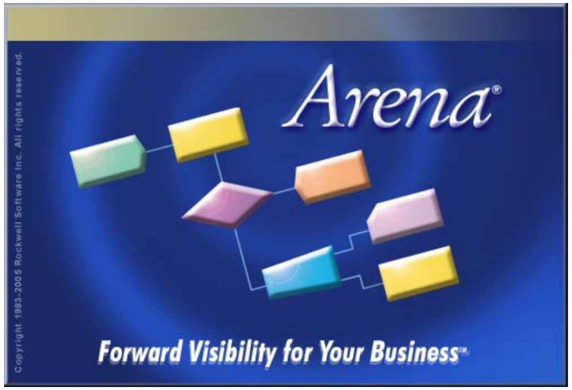
Discrete Event Simulation

- Why Discrete Event Simulation?
  - Cost Effective
  - Time Effective
  - Evaluate Multiple Alternatives
  - Evaluate the effects of uncertainty by averaging across many scenarios (days)



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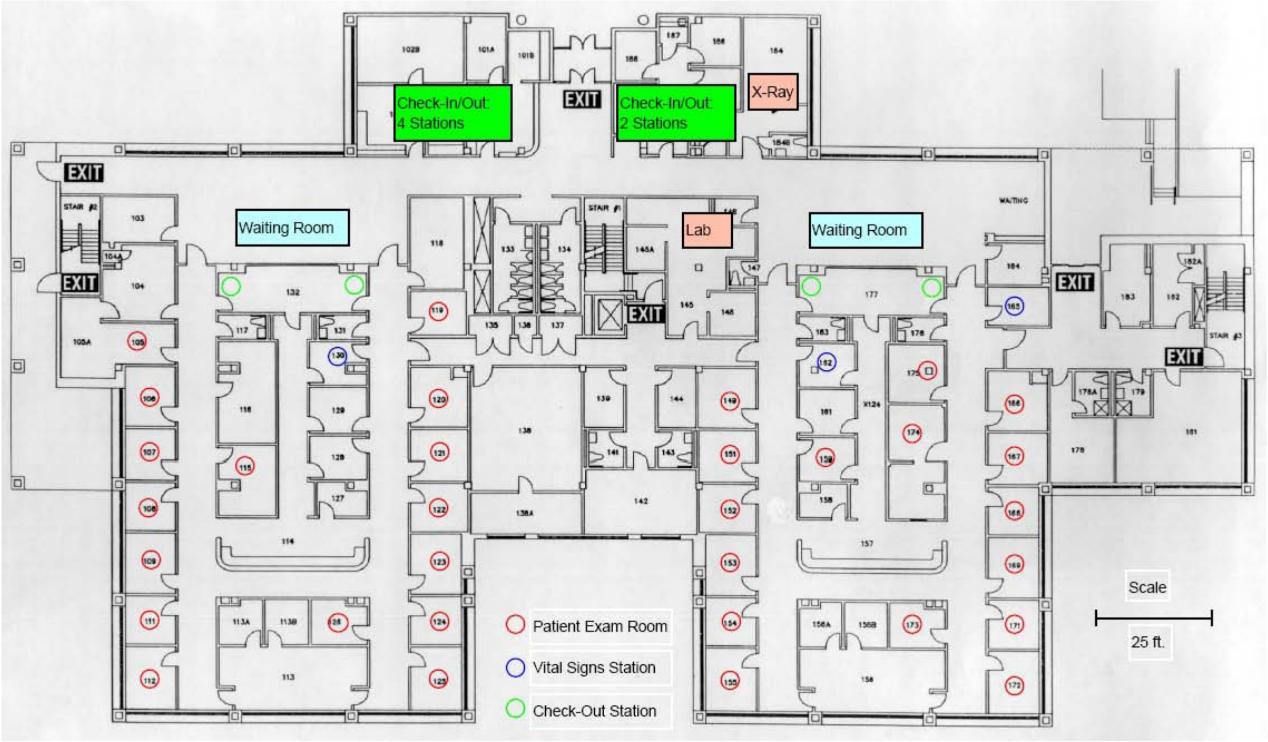
Creating a Conceptual Model

- On Site Meetings, Clinic Tour
- Track Process with Conference Calls



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Patient Flow and Resource Constraints

- Process Mapping:
  - Sequence of activities for typical patient flow
  - Alternative sequences and collections
  - Unpredictable events
- Potential Resource Constraints:

Exam Rooms	Vitals Rooms
Lab	Checkin/out
Physicians	Nurses
Preceptors	

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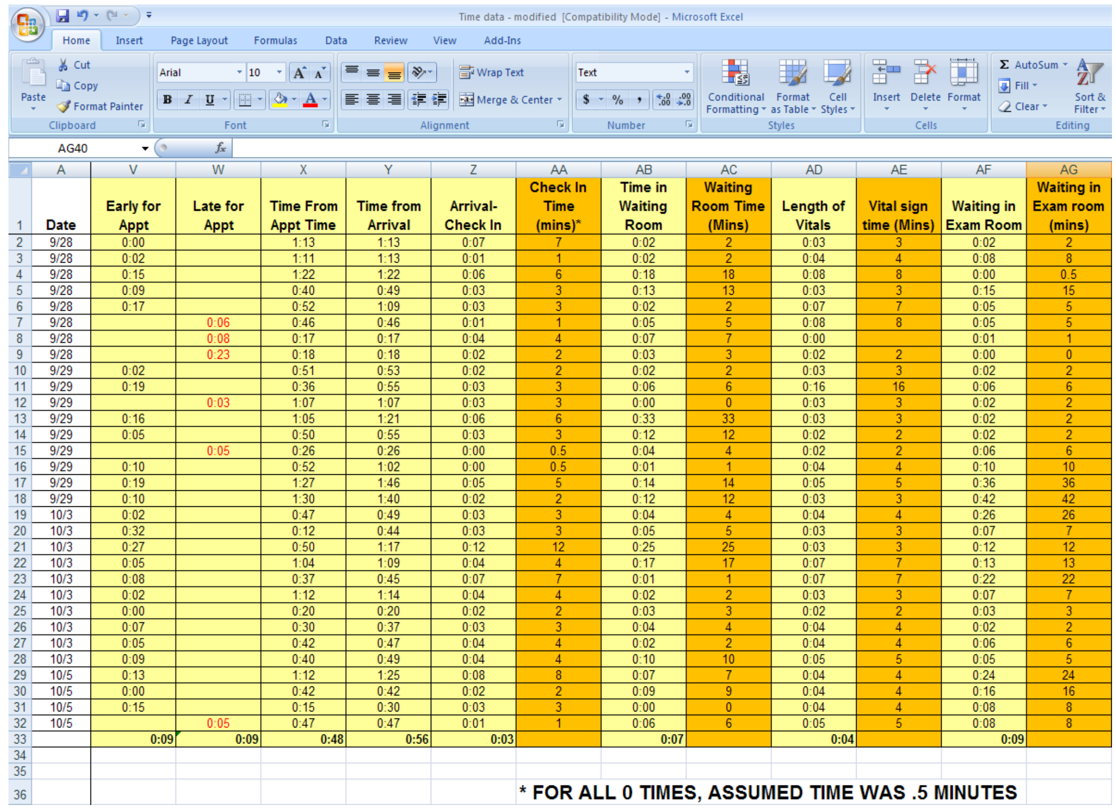
Creating a Data Model

- Large amounts of historical data required
  - Sampled activity times (e.g. patient with physician, patient with nurse, lab time, checkin/out times)
  - Probabilities
  - Arrival Schedule

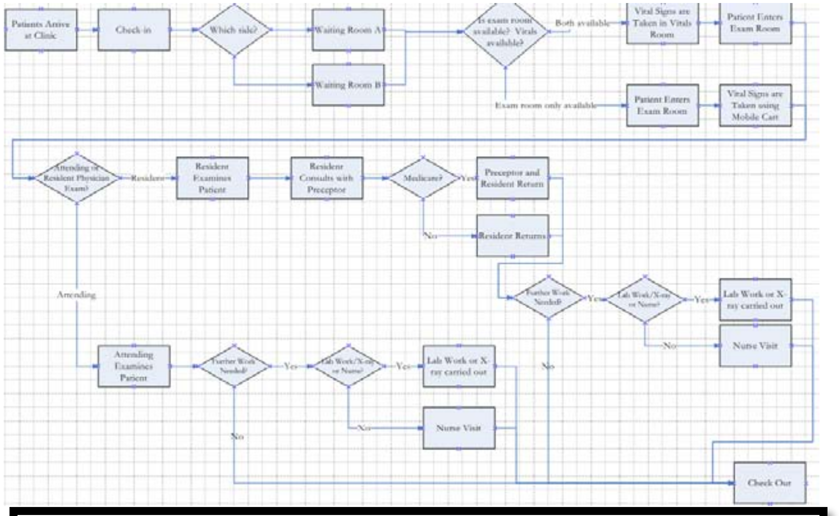


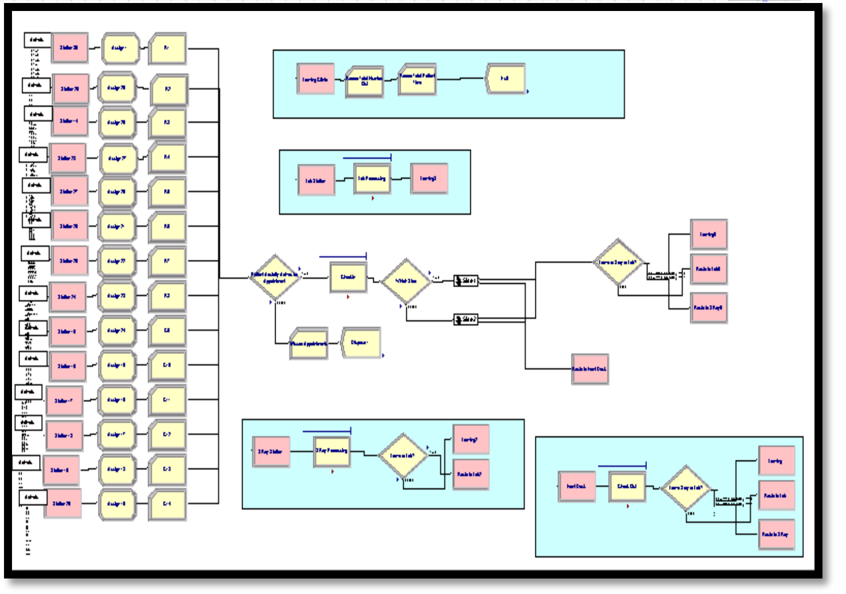
	Date	Early for Appt	Late for Appt	Time From Appt Time	Time from Arrival	Arrival-Check In	Check In Time (mins)*	Time in Waiting Room	Waiting Room Time (Mins)	Length of Vitals	Vital sign time (Mins)	Waiting in Exam Room	Waiting in Exam room (mins)
2	9/28	0:00		1:13	1:13	0:07	7	0:02	2	0:03	3	0:02	2
3	9/28	0:02		1:11	1:13	0:01	1	0:02	2	0:04	4	0:08	8
4	9/28	0:15		1:22	1:22	0:06	6	0:18	18	0:08	8	0:00	0.5
5	9/28	0:09		0:40	0:49	0:03	3	0:13	13	0:03	3	0:15	15
6	9/28	0:17		0:52	1:09	0:03	3	0:02	2	0:07	7	0:05	5
7	9/28		0:06	0:46	0:46	0:01	1	0:05	5	0:08	8	0:05	5
8	9/28		0:08	0:17	0:17	0:04	4	0:07	7	0:00		0:01	1
9	9/28		0:23	0:18	0:18	0:02	2	0:03	3	0:02	2	0:00	0
10	9/29	0:02		0:51	0:53	0:02	2	0:02	2	0:03	3	0:02	2
11	9/29	0:19		0:36	0:55	0:03	3	0:06	6	0:16	16	0:06	6
12	9/29		0:03	1:07	1:07	0:03	3	0:00	0	0:03	3	0:02	2
13	9/29	0:16		1:05	1:21	0:06	6	0:33	33	0:03	3	0:02	2
14	9/29	0:05		0:50	0:55	0:03	3	0:12	12	0:02	2	0:02	2
15	9/29		0:05	0:26	0:26	0:00	0.5	0:04	4	0:02	2	0:06	6
16	9/29	0:10		0:52	1:02	0:00	0.5	0:01	1	0:04	4	0:10	10
17	9/29	0:19		1:27	1:46	0:05	5	0:14	14	0:05	5	0:36	36
18	9/29	0:10		1:30	1:40	0:02	2	0:12	12	0:03	3	0:42	42
19	10/3	0:02		0:47	0:49	0:03	3	0:04	4	0:04	4	0:26	26
20	10/3	0:32		0:12	0:44	0:03	3	0:05	5	0:03	3	0:07	7
21	10/3	0:27		0:50	1:17	0:12	12	0:25	25	0:03	3	0:12	12
22	10/3	0:05		1:04	1:09	0:04	4	0:17	17	0:07	7	0:13	13
23	10/3	0:08		0:37	0:45	0:07	7	0:01	1	0:07	7	0:22	22
24	10/3	0:02		1:12	1:14	0:04	4	0:02	2	0:03	3	0:07	7
25	10/3	0:00		0:20	0:20	0:02	2	0:03	3	0:02	2	0:03	3
26	10/3	0:07		0:30	0:37	0:03	3	0:04	4	0:04	4	0:02	2
27	10/3	0:05		0:42	0:47	0:04	4	0:02	2	0:04	4	0:06	6
28	10/3	0:09		0:40	0:49	0:04	4	0:10	10	0:05	5	0:05	5
29	10/5	0:13		1:12	1:25	0:08	8	0:07	7	0:04	4	0:24	24
30	10/5	0:00		0:42	0:42	0:02	2	0:09	9	0:04	4	0:16	16
31	10/5	0:15		0:15	0:30	0:03	3	0:00	0	0:04	4	0:08	8
32	10/5		0:05	0:47	0:47	0:01	1	0:06	6	0:05	5	0:08	8
33		0:09	0:09	0:48	0:56	0:03		0:07		0:04		0:09	

* FOR ALL 0 TIMES, ASSUMED TIME WAS .5 MINUTES

Model Construction

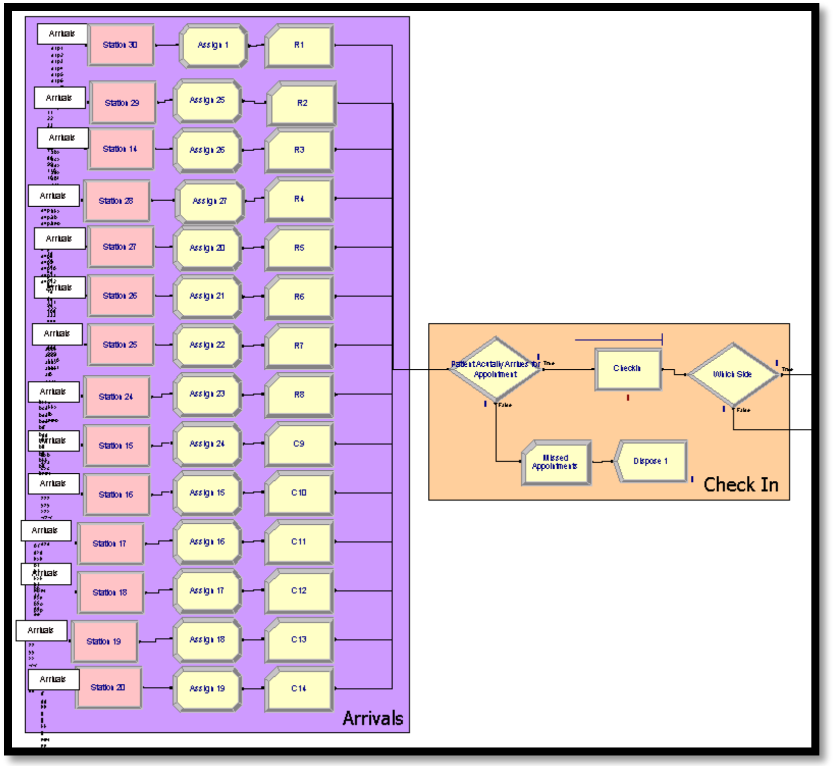
- The base model was constructed in modules
  - Arrivals and Check In
  - Waiting Area and Vital Signs
  - Exam Rooms and Examinations
  - Radiology, Laboratory, and Checkout
- The Model is divided into two sides with two halls per side



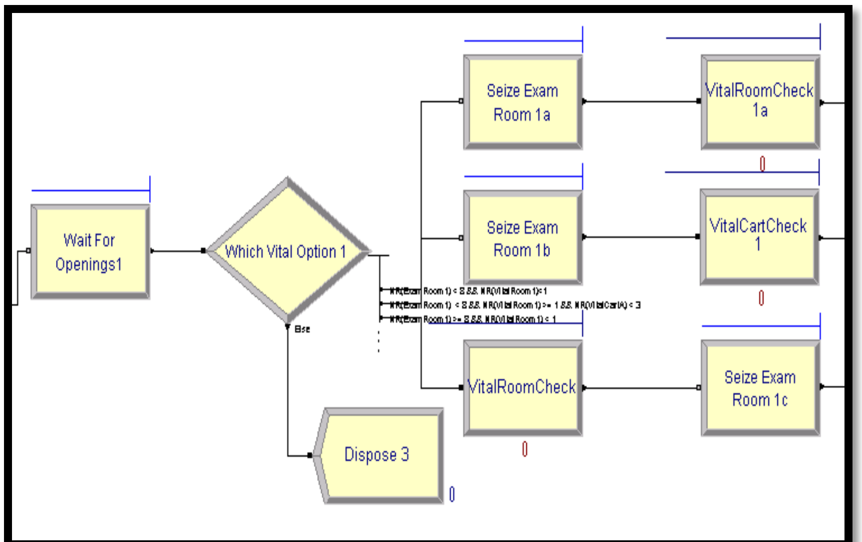


Arrivals and Check In

- Arrival of patients is determined by scheduling templates
- Each patient is assigned a specific physician and a number of other attributes based on a discrete distribution



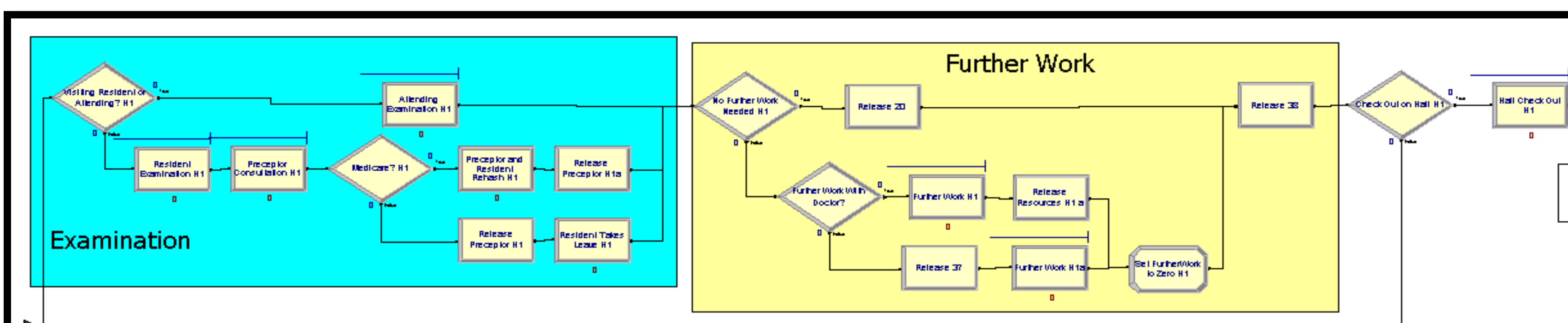
Resource Constraints: Waiting Area and Vital Signs



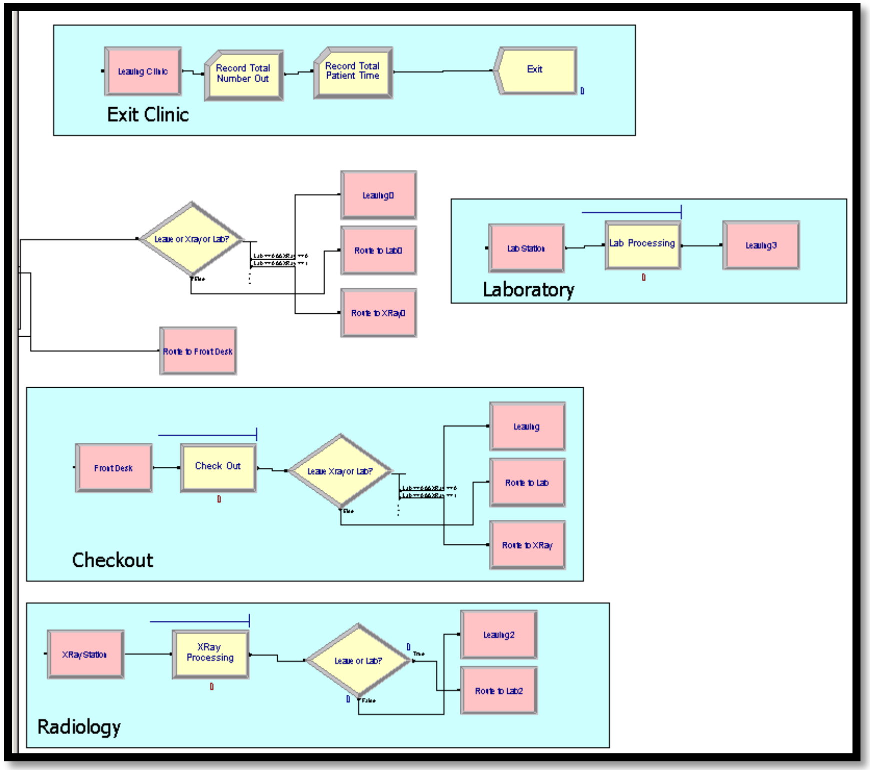
- Patients wait for one of two conditions to become true:
  - Vital room is available
  - Exam room and vital cart are available

Resource Constraints: Exam Rooms and Examination

- Patients wait for their physician to become available
- Resident procedure vs. Attending procedure
- Further Work
  - Only Nurse
  - Nurse and Physician
- Hall Checkout



Resource Constraints: Radiology, Laboratory, and Checkout



- After leaving the exam room, each patient has a probability of needing an X-ray and/or laboratory work
- If not already done, patient checks out then leaves the clinic

Staffing

- Staffing levels were determined through communication with Operations Manager Kevin Tate
  - Given the total number of resources
  - Determined a logical distribution of resources
- The base model uses the typical staffing levels

	Number of Resources		Number of Resources
Attending Doctors		**Exam Rooms**	
Hall 1	2	Hall 1	8
Hall 2	2	Hall 2	8
Hall 3	2	Hall 3	8
Hall 4	2	Hall 4	8
Residents		**Hall Check Out**	
Hall 1	2	Hall 1	1
Hall 2	1	Hall 2	1
Hall 3	2	Hall 3	1
Hall 4	1	Hall 4	1
Nurses		**Preceptors**	
Hall 1	4	Side 1	1
Hall 2	3	Side 2	1
Hall 3	4	**Vital Carts**	
Hall 4	3	Side 1	3
Vital Rooms		Side 2	3
Hall 1	1	**Front Desk**	6
Hall 2	1	**Radiology**	1
Hall 3	1	**Laboratory**	1
Hall 4	1		

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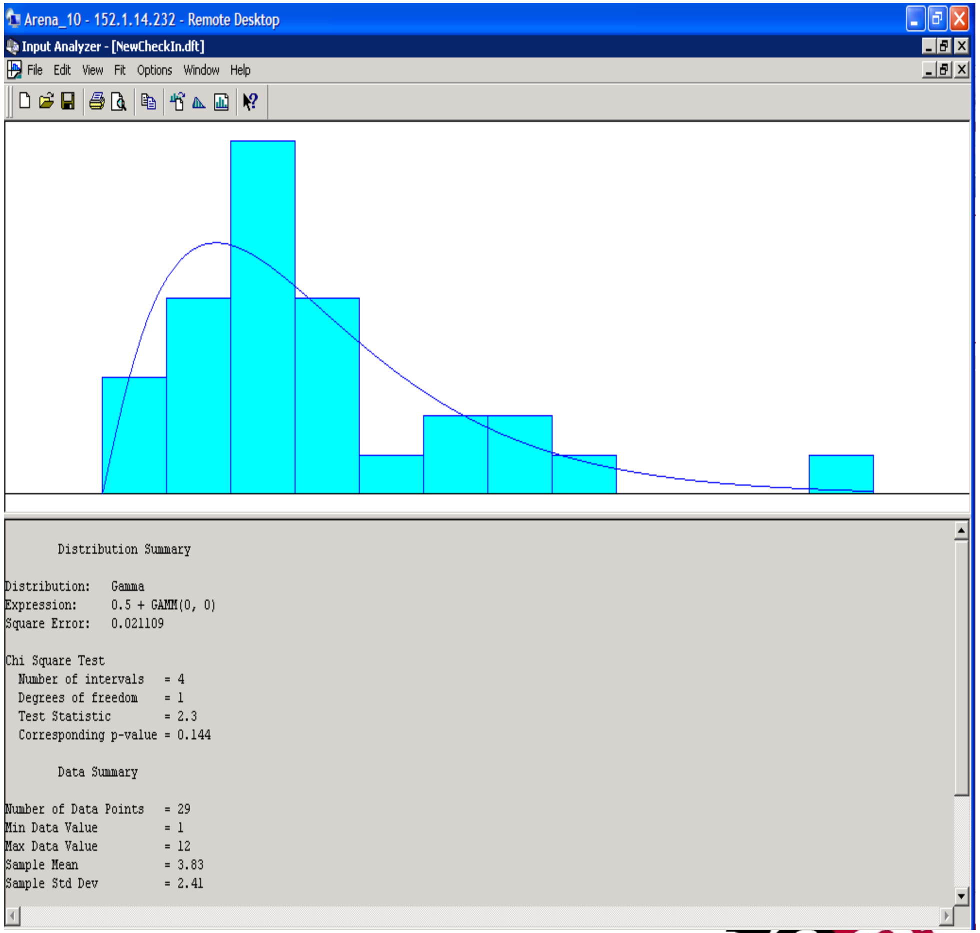
Process Time Distributions

- Time distributions for all process activities were determined using Arena Input Analyzer
  - Part of the Arena Software package
  - Allows fitting a distribution to a set of data



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Validation of Base Model

Base Model Results		
	Per Shift	**Per Day**
Patients	89.4	178.8
Throughput	85.2	170.4
Patients Left in Clinic	4.2	8.4
Cycle Time (min)	51.82	51.82
Wait Time (min)	10.6	10.6
Value Added Time (min)	37.55	37.55

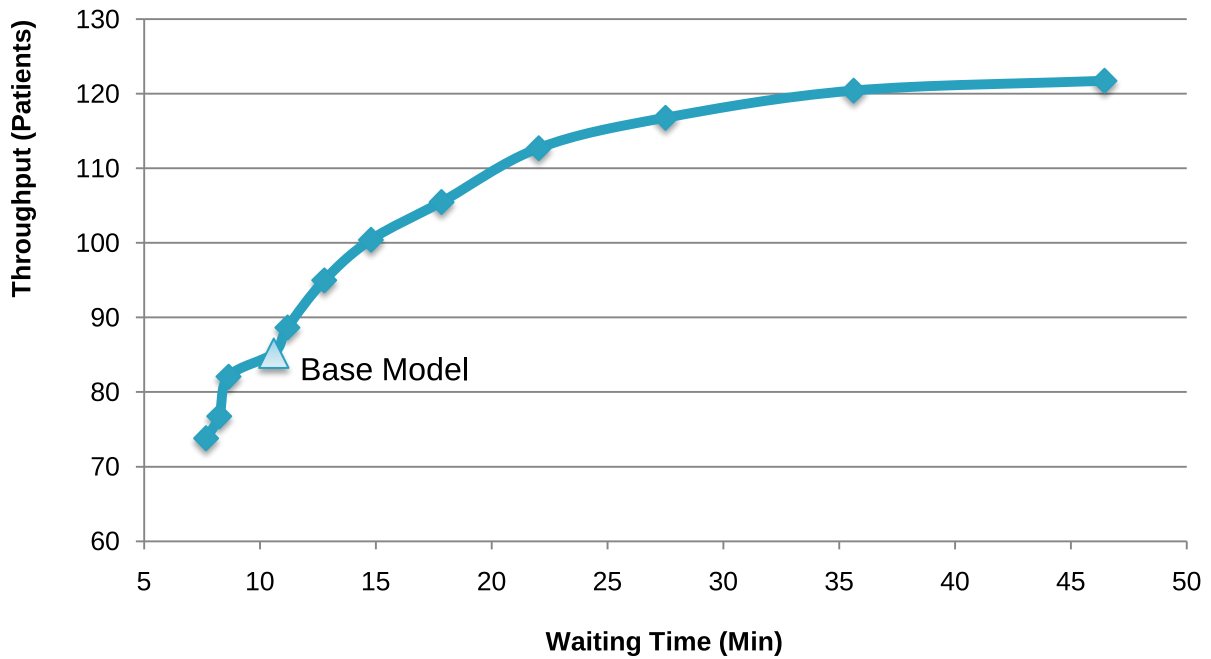
- A comparison of our values of the primary performance measures show that our model is valid.

- Both our base model and the clinic have patients left in the system at the end of a shift.

Performance Measures

We utilized two primary performance measures to validate our model:

- **Throughput:** number of patients who pass through clinic during a shift
- **Cycle Time:** how long patients are in the clinic
  - Waiting Time: time spent waiting for a resource to become available
  - Value Added Time: the amount of time spent with a resource



Results of Experiments

Experiment 1: Adding Two Physicians

- Base Model – 14 physicians per shift
  - 3 physicians on hallways 1 & 3
  - 4 physicians on hallways 2 & 4
- Proposed scenario: Adding two physycians
  - Adding one physicians to hallway 1
  - Adding one physicians to hallway 3
  - Result: Each hall has 4 physicians

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Results of Experiments

Results:

	Base Model	Adding Two Doctors
Throughput (patients)	85.2	99.02
Waiting Time (minutes)	10.6071	10.5814

– Resources accommodated the higher volume

Recommendation: hire two additional physicians

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Results of Experiments

Experiment 2: No hall checkout rooms

	Base Model	No Hall Checkout Rooms
Throughput (patients)	85.2	85.63
Waiting Time (minutes)	10.6071	10.4408

Recommendation: Convert the hall checkout rooms for other uses

Results of Experiments

Experiment 3: Altering number of exam rooms per hall

	Base Model	7 Exam Rooms	9 Exam Rooms
Throughput (patients)	85.2	85.36	85.26
Waiting Time (minutes)	10.6071	10.5466	10.6287

Recommendation: Do not add additional exam rooms

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Results of Experiments

Experiment 4: Staggered Shifts

- Base model – 2 shifts
  - 8 AM – 12 PM; 1 PM – 5 PM (approximate)
  - 14 physicians each shift
- Adding a third shift
  - Shift 1: 8 AM – 12 PM, 9 physicians
  - Shift 2: 10 AM – 2 PM, 10 physicians
  - Shift 3: 12 PM – 4 PM, 9 physicians
- Desired result: help smooth scheduling

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Results of Experiments

Results:

	Base Model	Adding a Third Shift
Daily throughput (patients)	170.4	164
Waiting Time (minutes)	10.6071	10.5814

Recommendation: Do not stagger shifts

Summary

- Some things that seemed like obvious ways to improve the system were not
- The model building process generated many more ideas for experiments
- Evaluation of new ideas is now "cheap"

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A Surgery Scheduling Decision Support System

North Carolina State University
Edward P. Fitts Department of Industrial and Systems Engineering
Senior Design Project

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Sponsored by:
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Advised by:
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April 23, 2008

Project Goal

- Develop a decision support system for automated surgery scheduling
- Design a heuristic for computing near optimal surgery schedules given OR and scheduling constraints
- Enable decision makers to manually change surgery schedules
- Provide advanced performance measures for the analysis of surgery schedules

Problem Description

- Thoracic Unit Surgery Scheduling
  - 4 primary surgeons, multiple residents
  - 22 different procedures
  - Average of 1,500 patients per year
  - Typically 6 operating rooms
- Current method
  - Manual
  - No formal heuristic used

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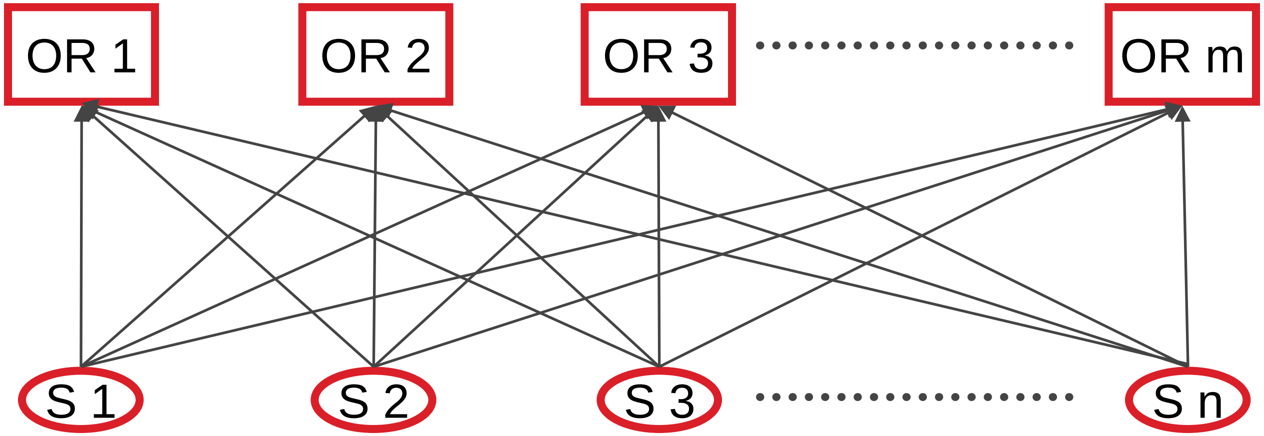
Multi-Operating Room Scheduling



Decisions:

- How many ORs to open?
- Where to schedule each surgery?

Performance Measures:

- Cost of operating rooms opened
- Overtime costs for operating rooms

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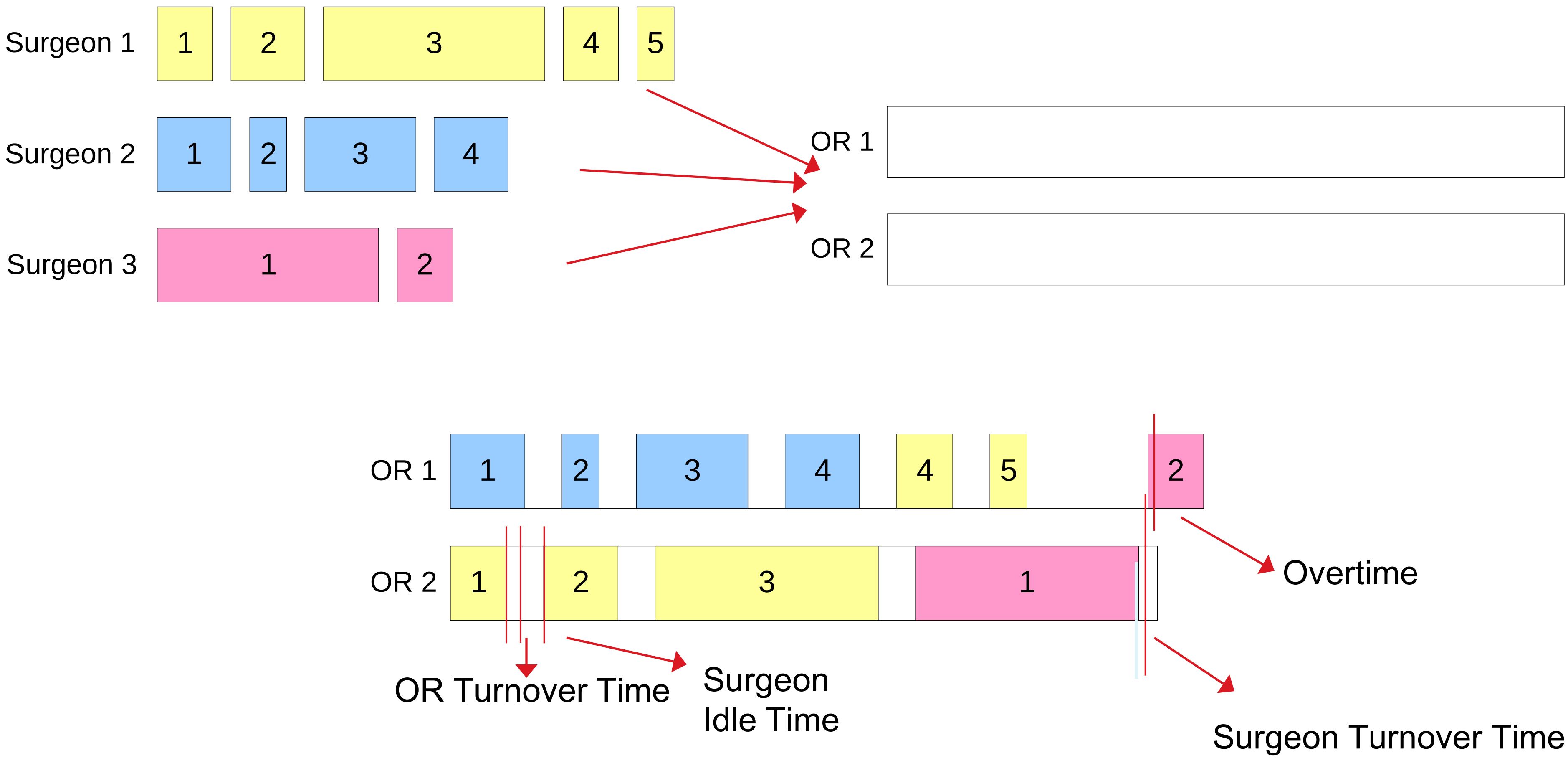
Resource Constraints



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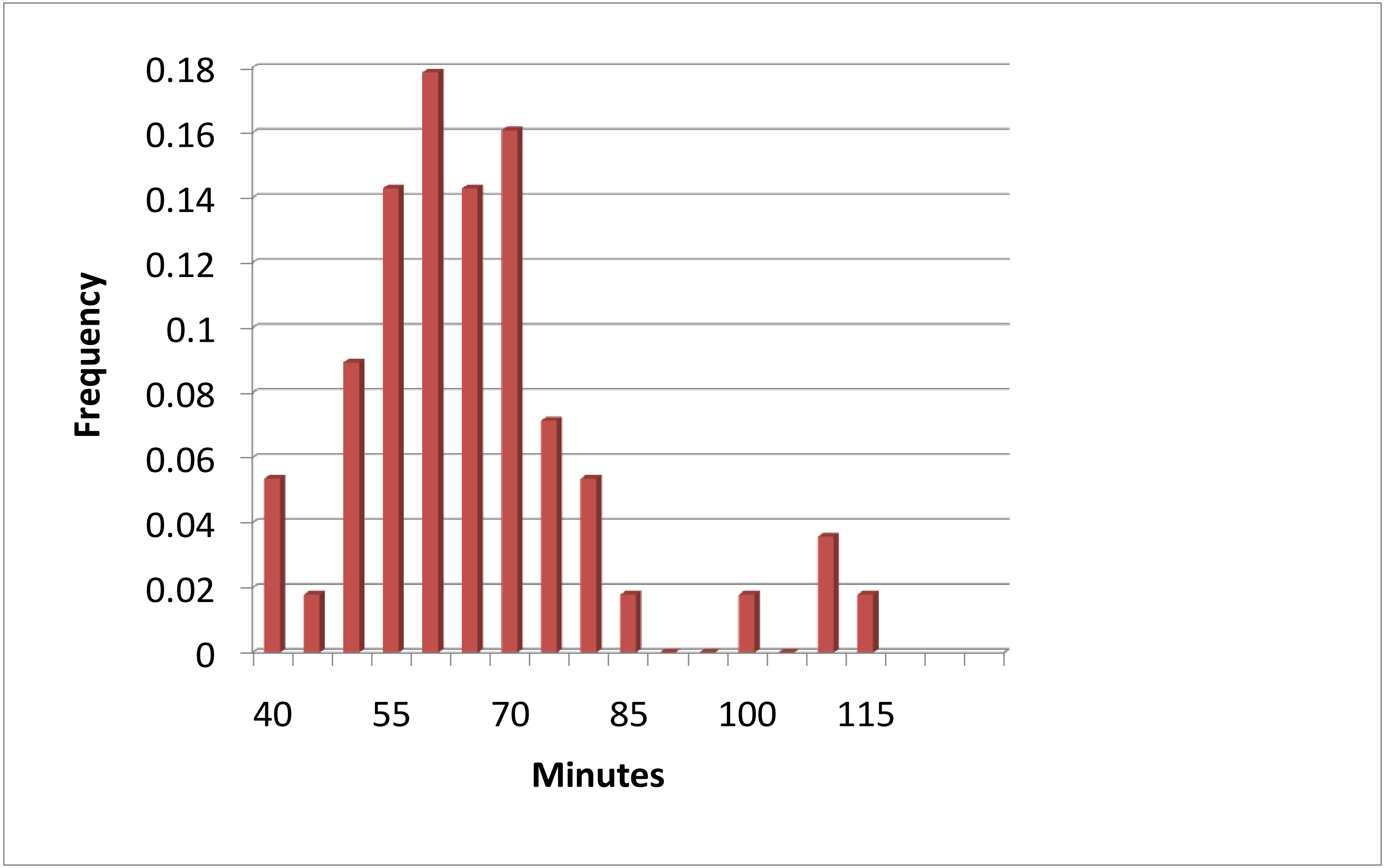
Surgery Duration Variability



Simulation Model

- A Discrete event simulation model
  - Inputs:
    - Automatically generated or user selected surgery schedule
    - User defined parameters (# of ORs, # of surgeries, type of surgeries, cost of OR, cost of overtime)
  - Outputs:
    - Average overtime
    - Probability of overtime in each OR
    - Total cost (cost of ORs + cost of overtime)

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Data Sampling

- 22 Different Types of surgeries
  – Various combinations
  – Up to five surgeries per patient

- Over 3 million combinations
- “Scenarios” generated by statistical sampling from historical data

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Automated Scheduling Algorithm

- Compute mean duration for each patient
- Group by resident surgeon
- Select the lower bound number of OR's needed
- Schedule resident with longest duration to least loaded OR
    - Repeat until all residents have been scheduled
- Compute over time statistics
- View optimized schedule

Algorithm Example

	Sample Surgery Time (mins)	Resident
Patient 1	100	1
Patient 2	120	2
Patient 3	300	3
Patient 4	150	5
Patient 5	110	6
Patient 6	75	1
Total Time	**855**	

[redacted]

$$Minutes\ per\ day = 9\ hours * \frac{60\ min}{hr} = 540\ minutes$$

$$Number\ of\ ORs = \frac{Surgery\ Minutes}{Minutes\ per\ day} = \frac{855\ min}{540\ min} = 1.583 = 2$$

Algorithm Cont.

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[redacted]

[redacted]

[redacted]

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Algorithm Cont.

[redacted]

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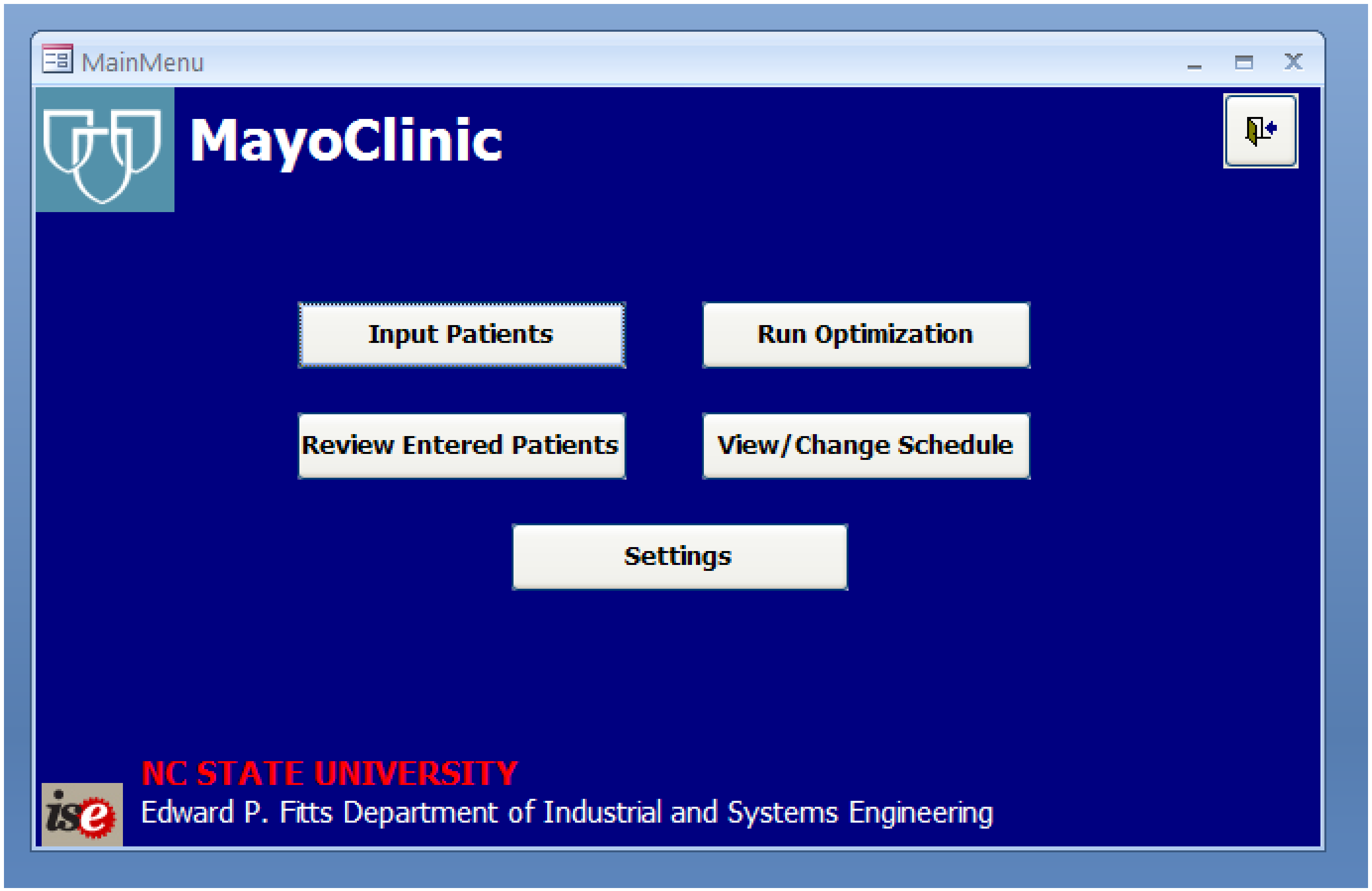
Algorithm Cont.

- Allowable overtime is set by user
- If any OR's time exceeds the max allowable time in minutes:
  - (1) increase the number of open OR's by one
  - (2) recalculate the new schedule
- Return the best (minimum cost) schedule found

Demo


MainMenu
MayoClinic
Input Patients
Run Optimization
Review Entered Patients
View/Change Schedule
Settings
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DSS Scheduling vs. Current Scheduling

	Actual Rooms Opened	Actual Base Cost	DSS Rooms Opened	DSS Cost
1/3/2005	4	$ 17,748	3	$ 15,165
1/4/2005	6	$ 26,622	5	$ 24,997.00
1/5/2005	4	$ 17,748	3	$ 14,322.00
1/6/2005	3	$ 13,311	4	$ 18,946.00
1/7/2005	4	$ 17,748	4	$ 18,207.00
1/26/2005	4	$ 17,748	3	$ 15,349.00
11/13/2006	5	$ 22,185	4	$ 20,415.00
11/14/2006	4	$ 17,748	2	$ 9,148.00
11/15/2006	6	$ 26,622	4	$ 18,430.00
Total Cost		$ 177,480		$ 154,979
Average Savings/Day		**$ 2,500**		
Average Savings/Year		**$ 912,540.56**		

Summary

- There are many opportunities to use systems engineering methods to improve health care delivery
- Environments that are “data rich” are well positioned to use systems engineering
- A small number of (the right) resources can go a long way!