Discrete Event Simulation for Process Improvement: Emergency Department Flow

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17 January, 2012

Outline

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- Acknowledgements

Conflict of Interest

- None.

Funding Source

- QI, not funded research
- Software licenses, computers provided by 2009 VHA Innovations Award, Greenfield Incubation #123

Introduction

- Challenges in Medicine
  - How do we treat all of our patients?
  - How do we decide where to dedicate resources?
  - What performance measures are appropriate?
- Systematic approach to answers
  - "What if?" and "How would?"
  - A different paradigm for hypothesis testing
- How can we reduce the number of long stays at the St. Louis VAMC Emergency Department?

Driving Questions

- Can we reduce average length of stay, and the proportion of patients with very long stays, by allowing provider assessment and disposition from triage?
  - Literature suggests so[1]!
  - Addition of mid-level providers to triage
  - Discharge from triage
  - Enhanced use of provider based fast-track

1) Wiler JL, Gentle C, Halfpenny JM, Heins A, Mehrotra A, Mikhail MG, Fite D(2010) *Ann Emerg Med* 55(2):142-160.e1

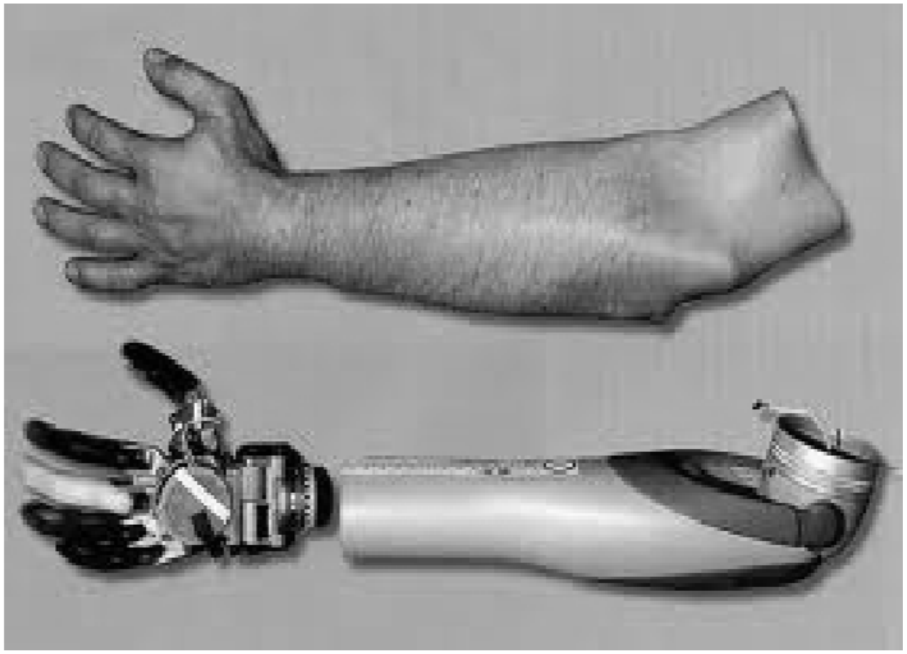
Driving Questions

- Can we assess the likelihood of success prior to experimentation?
  - Discrete Event Simulation (DES) has been employed in EDs before
  - Useful for prediction of patient throughput times[2]
  - Comparison of triage practices[2]
  - Economic Evaluation[3]

2) Connelly LG, Bair AE, (2004) *Acad Emerg Med* 11(11):1177-85.
3) Caro JJ, Möller J, Getsios D, (2010), *Value in Health* 13(8):1056-1060.

Systems Engineering in Medicine

- Many people think of Biomedical Engineering…



Simulation in Medicine

Systems Engineering in Medicine

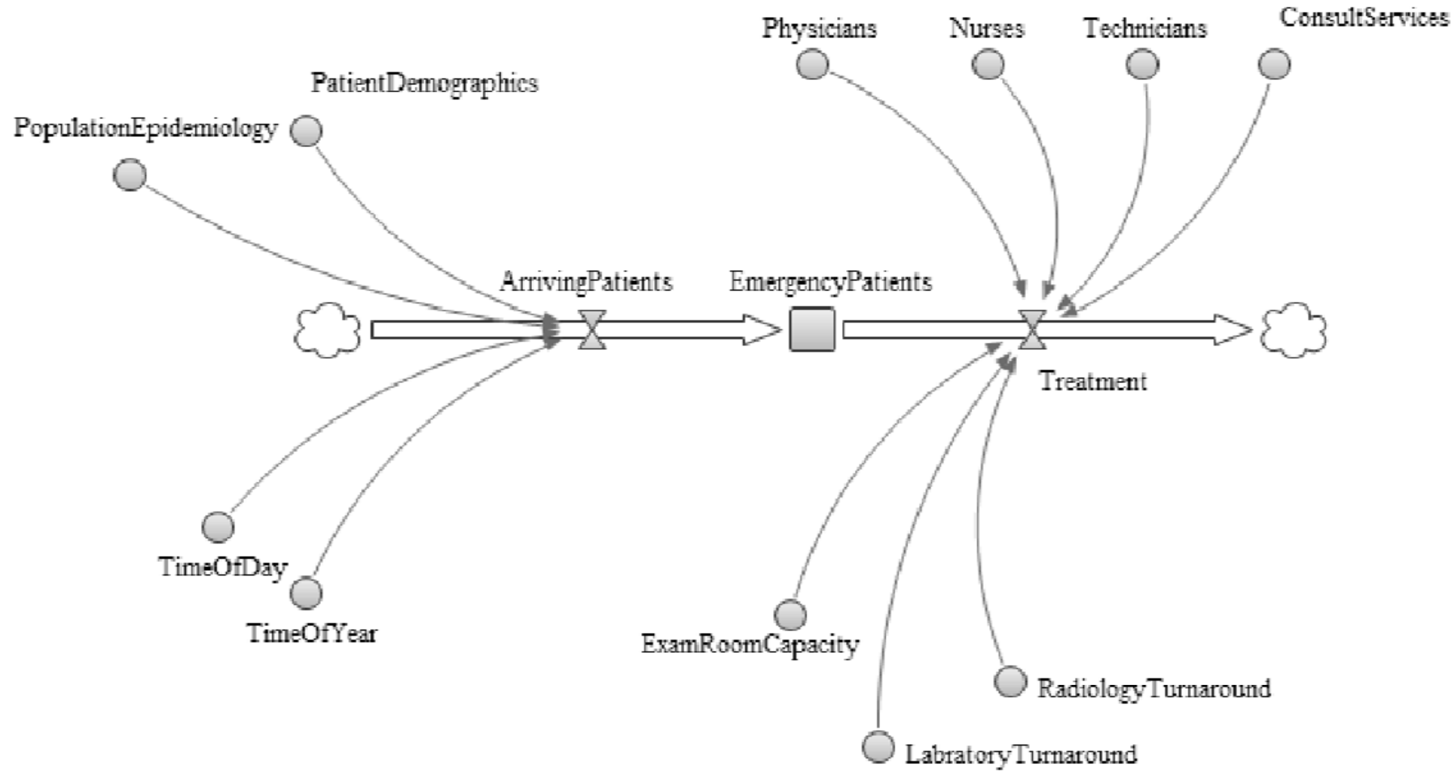
- Definition, System:
  - "A collection of objects and relationships"
- Definition, Systems Engineering:
  - "An interdisciplinary approach and means to enable the realization of successful systems"[4]
- Study and design of large scale systems

4) Systems Engineering Handbook; a "what to" guide for all SE practitioners
INCOSE-TP-2003-016-02, Version 2a, 1 June 2004.

Systems Engineering in Medicine

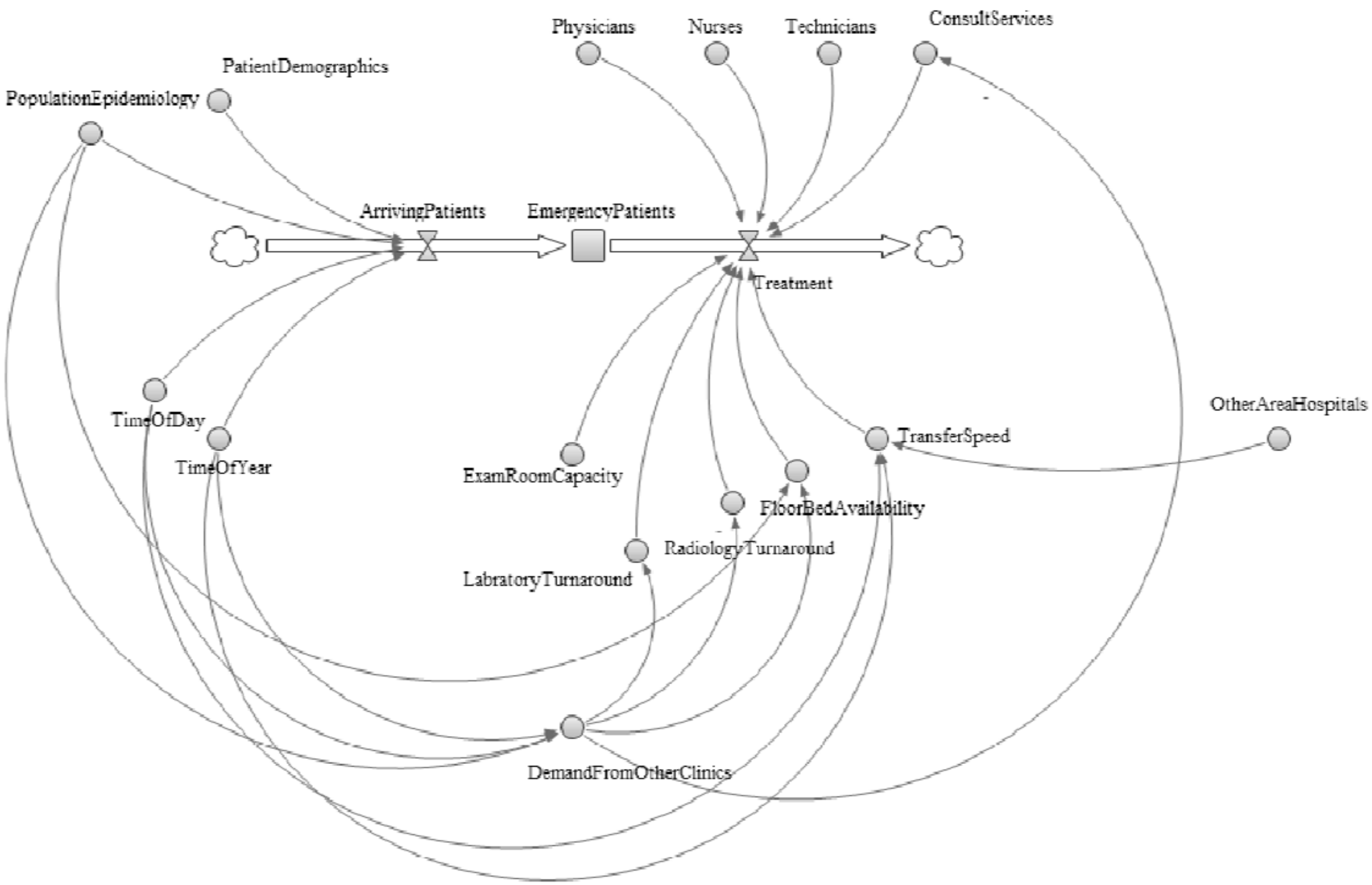
- Optimization of systems with human actors
  - How do decision makers make decisions?
- Analysis of competing objectives
  - Cost, quality
  - Speed, safety
- Examination of constraints, bottlenecks, barriers to care
  - Capacity
  - Policies and Regulations

Medical Systems as Dynamic Systems



Basic Emergency Department Model?

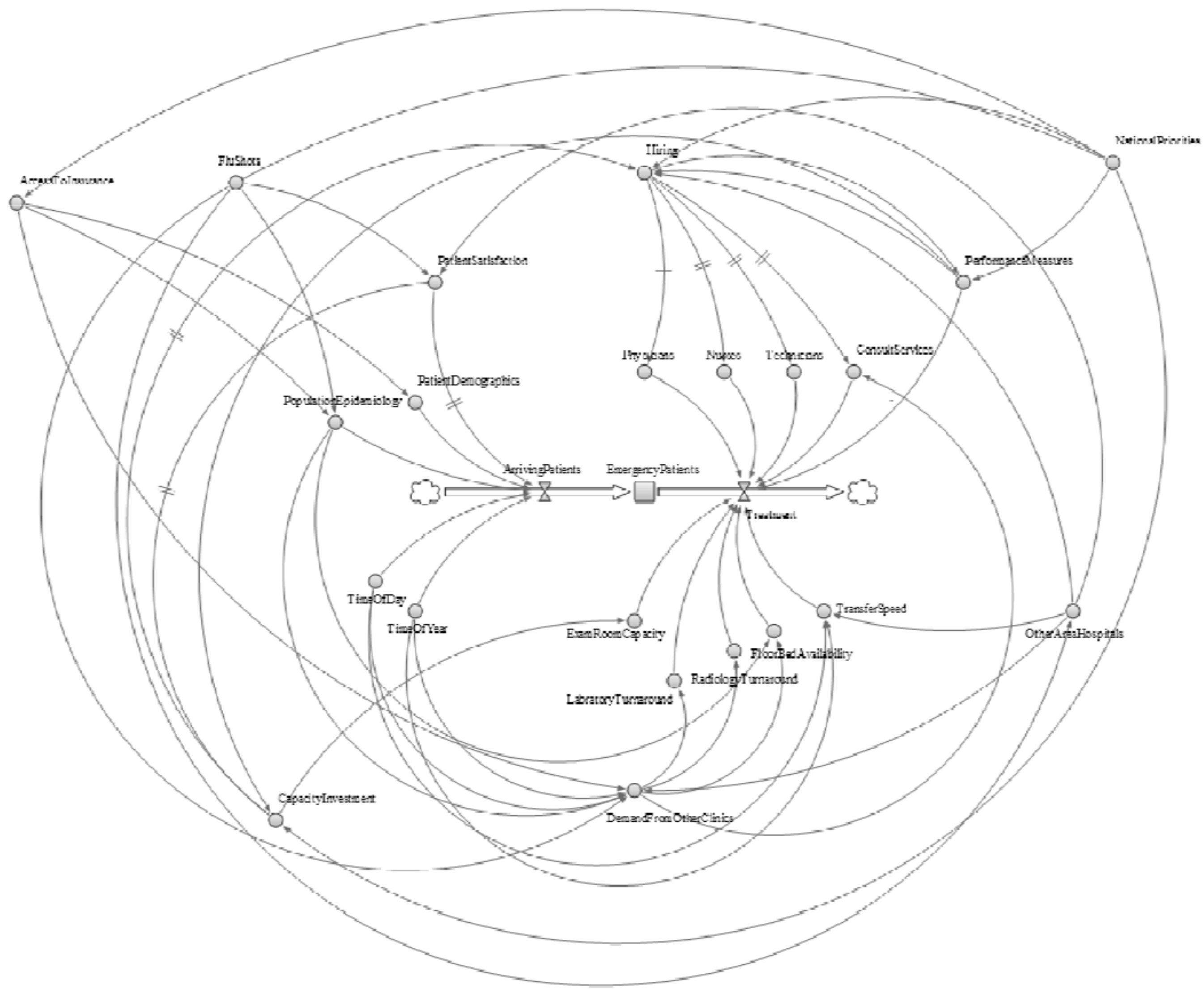
Medical Systems as Dynamic Systems



Basic Emergency Department Model?

Medical Systems as Dynamic Systems

- •Multiple Dependencies
- •Complex Interactions
- •Dynamic Behavior
- •"Butterfly Effect"
- •Feedback Loops
- •Adaptive
- •Memory Dependant
- •Nonlinear State Variables
- •Indistinct Boundaries



What is Complexity?

- Multiple independent subsystems
- Adaptivity
- Emergent behavior
- Propagating consequences
- Semi-periodicity

Modeling Dynamic Systems

- Multi-stage process
- Direct observation and archival data
- Multiple methods
  - Systems Dynamics
  - Agent Based Modeling
  - Discrete Event Simulation
- Stochastic

Discrete Event Simulation

- *Stochastic*: some state variables are random
- *Dynamic*: time evolution is important
- *Discrete-Event*: significant changes occur at discrete time instances

Discrete Event Simulation

- Provides real time visualization of dynamic system
- Allows medical personnel to critique and improve system fidelity
- Visual indication of problem areas allows non-engineers to identify bottlenecks and propose solutions

System Capture

- Clinic decomposition
  - Locations
    - Exam rooms, waiting rooms, offices
  - Resources
    - Doctors, nurses, technicians, equipment
  - Entities
    - Patients, paper records, phone calls

System Analysis

- Development of Flow
  - How do Entities consume Resources at Locations?
  - How do Entities proceed to the next Location?
  - How do Resources search for tasks?
- Location and Staff Capacities
  - Single Entity, Multiple Entity, Infinite Entity
  - Batchable Processes
- Queue Development
  - How do Entities wait while desired Resources are unavailable?

Data Acquisition

- Measured data
  - Observing resources, personnel
  - Observing locations, activities
- Archival data
  - Patient encounter sheets
  - Monthly status reports

Model Verification

- Model verified by clinic staff, and by input/output identification
- External Validation
  - Throughput metrics
  - Patient demography/statistics
- Internal Validation
  - Code Review
  - System Stress Tests

Simulation of the St. Louis VAMC Emergency Department

- Medium Sized ED
  - Level 3 Trauma Facility, 120 inpatient beds
  - 20,000 patient visits per year
  - 14 emergency patient beds
  - 2 beds dedicated for mental health emergency
  - 2-4 physicians, 4-11 RNs varying by time of day

The Problem:

- National Performance Measure Adherence
  - No more than 10% of patients should have stays longer than 6 hours (%LOS>6)
  - St. Louis VAMC ED was averaging 19.9%
- Daily mean length of stay was 247 minutes.
- Long stays are associated with increased morbidity, mortality, and eloping in the literature[5,6].

5) Ackroyd-Stolarz S, Read-Guernsey J, Mackinnon NJ, Kovacs G, (2011) *BMJ Qual Saf; 20(7):564-569*
6) Fernandes CM, Daya MR, Barry S, Palmer N (1994), *Ann Emerg Med* 24(6):1092–96

The Proposal

- Intervention consisted of change to triage practices
  - Consolidation of Fast Track with Triage
  - Placement of Physician and Mid-Level provider at triage
  - Treatment and disposition of ESI 4,5 directly from triage
  - Treatment and disposition of roughly 30% of ESI 3 from triage

Addressing the Problem with Simulation

- Simulate current practice
  - According to described process
- Validate simulation against current practice
  - Data used to generate model cannot be used to validate model: disjoint data sets required
- Simulate proposed change to system
  - Most effective for single changes
  - Multiple simultaneous changes not recommended

Simulation of Current Workflow

- Model informed by data, observation, interview
- Validated against 6 weeks of real-world data
  - 18 Sept – 30 Oct 2009
- Used to predict a 6 week simulated trial period
- Implementation adopted based on simulation results

Pre Intervention Flow

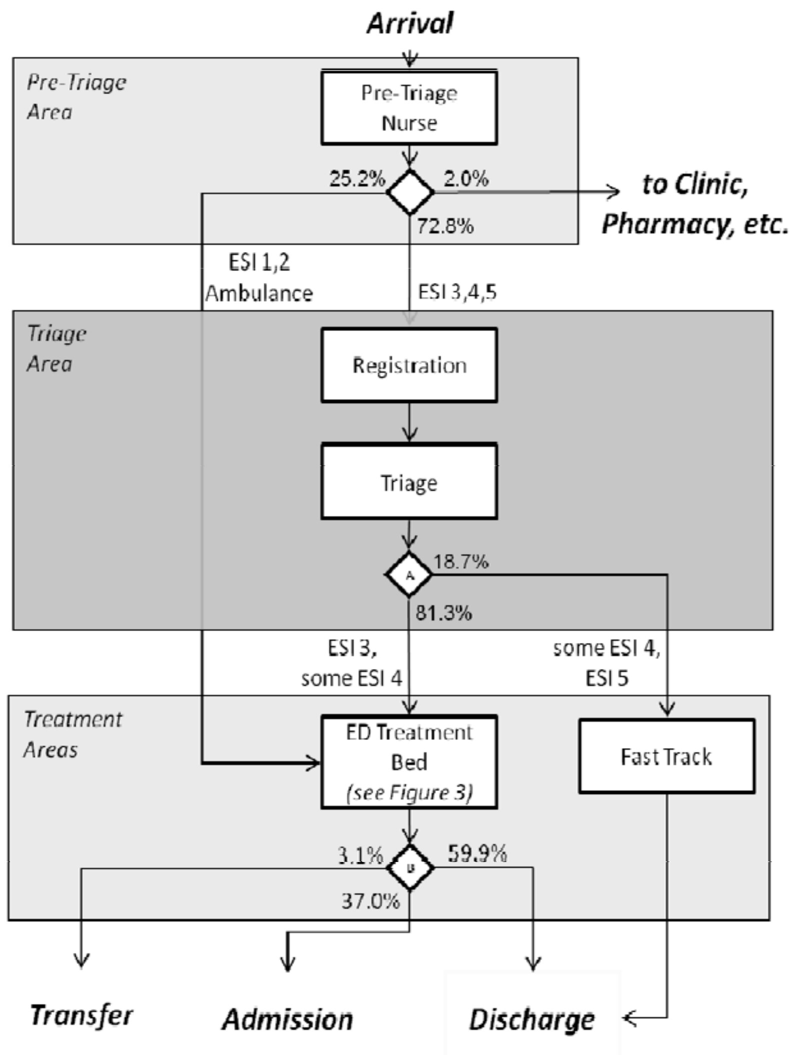


Figure 1: Pre Intervention Flow

Post Intervention Flow

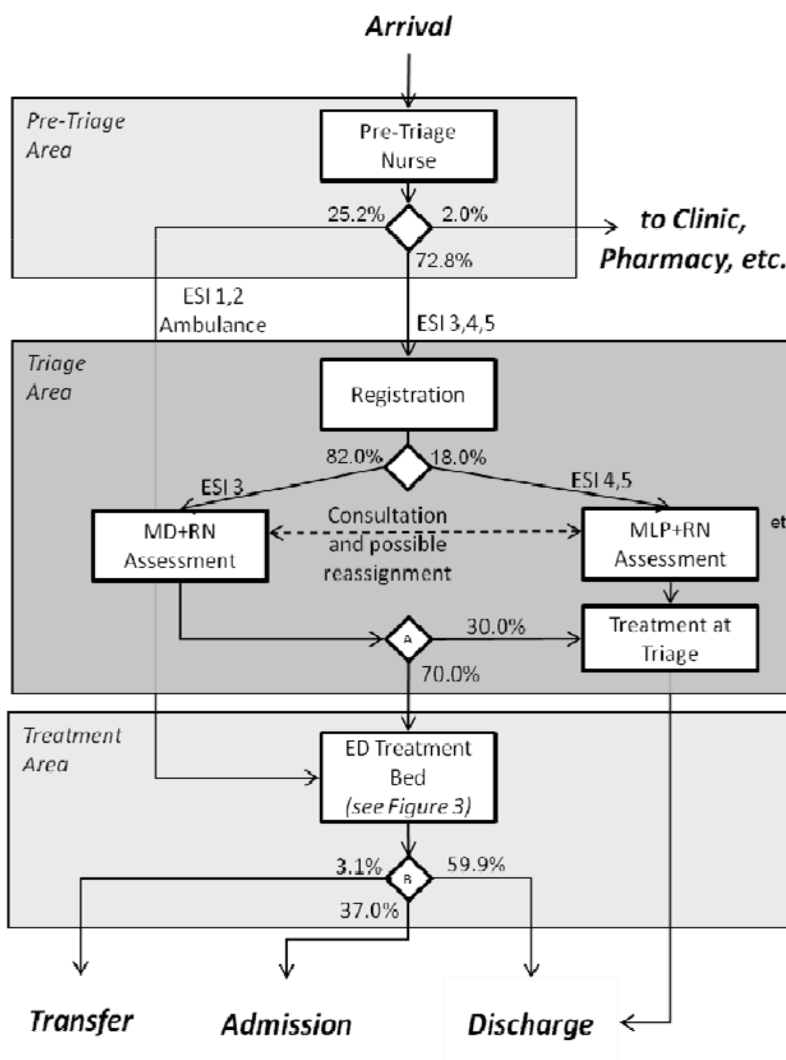


Figure 2: Post Intervention Flow

Flow Common to both Models

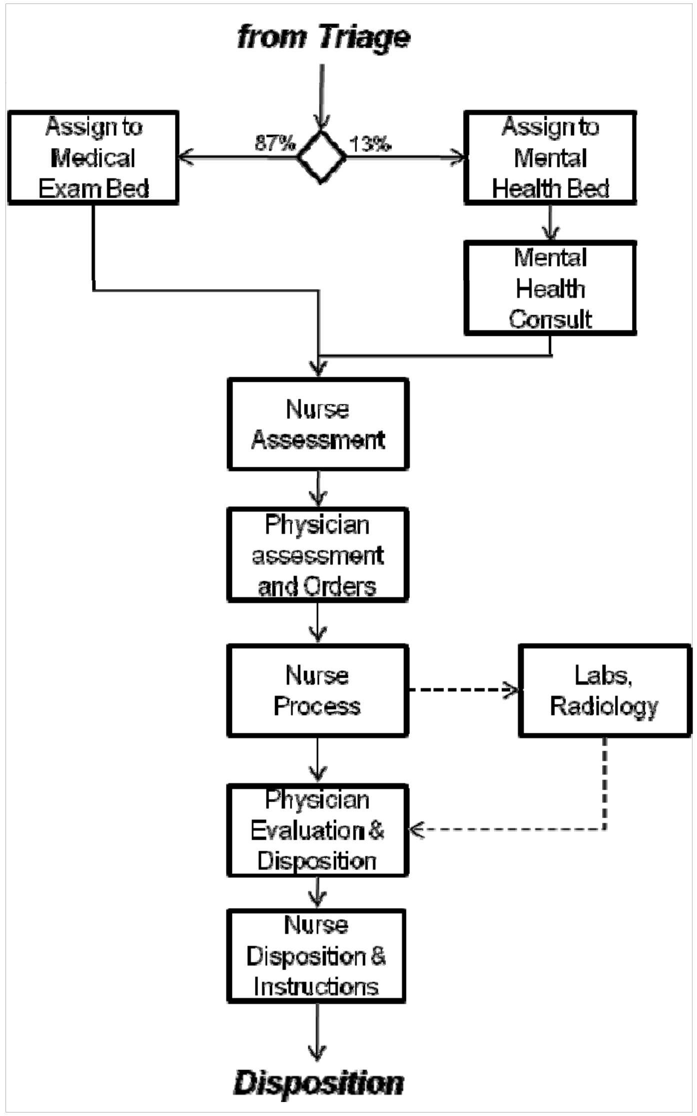


Figure 3: ED Bed Processes

Simulation

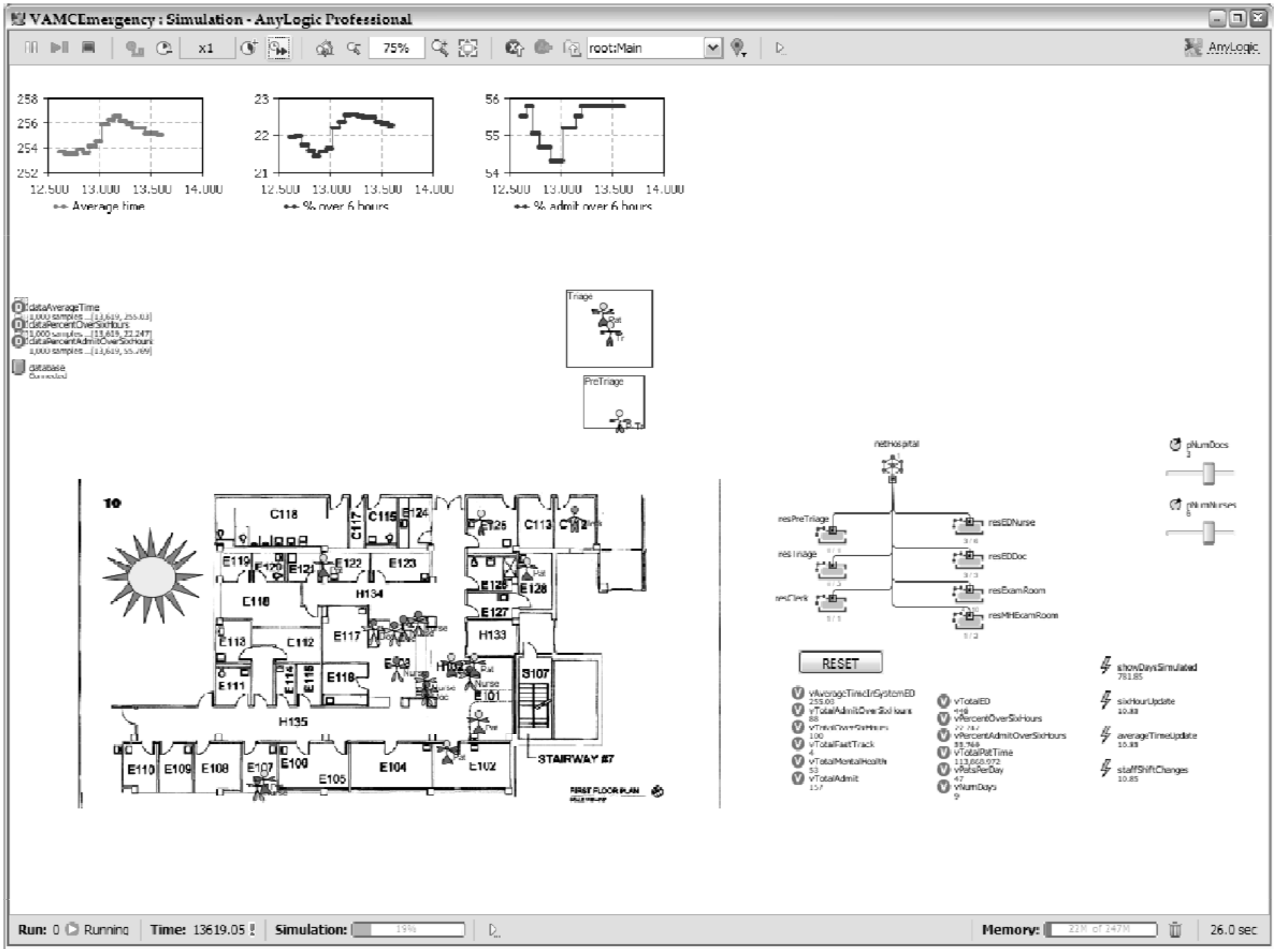


Figure 4: Simulation Screen

Validation

- Comparison of throughput metrics
  - Simulation Mean Daily LOS: 249 (39.7) min
  - Real World pre-intervention: 247 (39.8) min
    - p=0.694
  - Simulation %LOS>6: 19.9%
  - Real World pre-intervention: 19.0%
    - p=0.909
  - We <u>want</u> non-significance!

Accuracy of Prediction

- Implementation adopted for a 30 day trial from Oct 1 to Oct 30, 2010
  - Predicted daily mean LOS: 200 (19.0) min
  - Actual daily mean LOS: 210 (16.6) min
    - p=0.499
  - Predicted %LOS>6: 13.1%
  - Actual %LOS>6: 14.3%
    - P=0.880
  - We <u>want</u> non-significance!

Quality of Intervention

- Decrease in daily mean LOS of 37 minutes
  - $p<0.0001$
- Relative decrease in %LOS>6 of 28.2%
  - $p=0.045$
- No indications of negative effects on patient health, satisfaction

Limitations

- It is impossible to capture every possible variation in flow
  - Simulations are designed to capture normal practices
- Limited sample sizes
  - Patient cohorts of n=2194 and n=1699 respectively in test and trial periods

Limitations

- Some time distributions estimated from ED staff interviews
  - Possible introduction of recall bias
- No access to Protected Health Information
  - We don't know the how important factors like patient age, or history might be to LOS
  - Given the accuracy of prediction, it appears that factors other than ESI are likely to be less significant than PHI-related factors

Conclusion

- Discrete Event Simulation is a useful tool for examining Complex Systems
  - Must be thoroughly validated
  - Relies on assumptions
  - Focused on narrow predictions
- System improvements can be achieved while minimizing risk
  - Financial risk
  - Risk to patients

Acknowledgements

- VHA Innovations Program
  - Provided computers, software licenses.
- Abdul Rahim Al-Roubaie, MD
  - Chief of Emergency Medicine, St. Louis VA Medical Center
- Bradley Black, RN
- Tommie Strong, BS