Resource Scheduling through Resource-Aware Simulation of Emergency Departments

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Efficient Resource Use: Important but Hard

- Organizations need to be efficient
  - Requires efficient use of resources
- But their resources are very diverse
  - Humans
  - Machines
  - Software
  - Materials
- And subject to many complex constraints
  - Time
  - Budget
  - Domain-specific policies

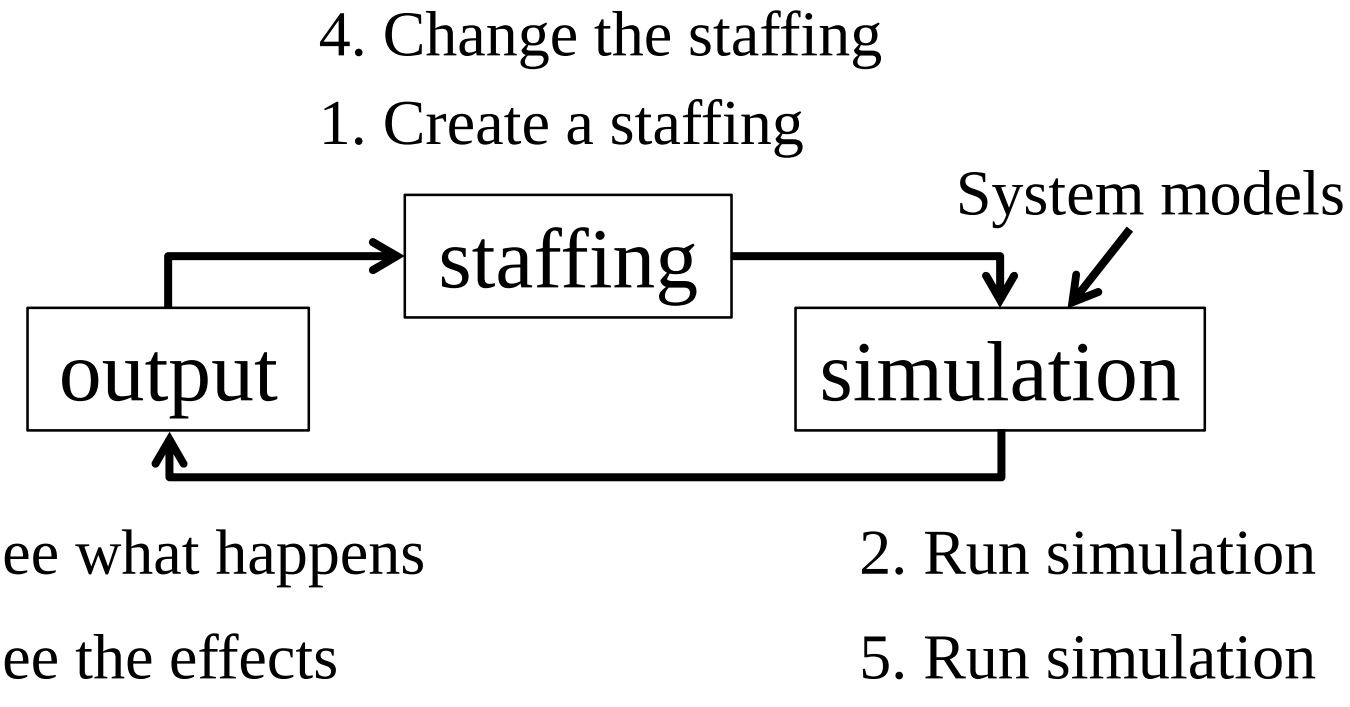
Resource Scheduling Problem

- Assigning resources to tasks
  - Subject to constraints
  - Aimed at optimizing an objective function
  - NP-hard
- Computational complexity
  - Exponential search space in the number of the resources
  - No efficient search to find optimal solutions
- Dynamic context
  - Environment change
  - Resource capability change

Discrete-Event Simulation

- Decision making process

- How do we guide staffing decisions?

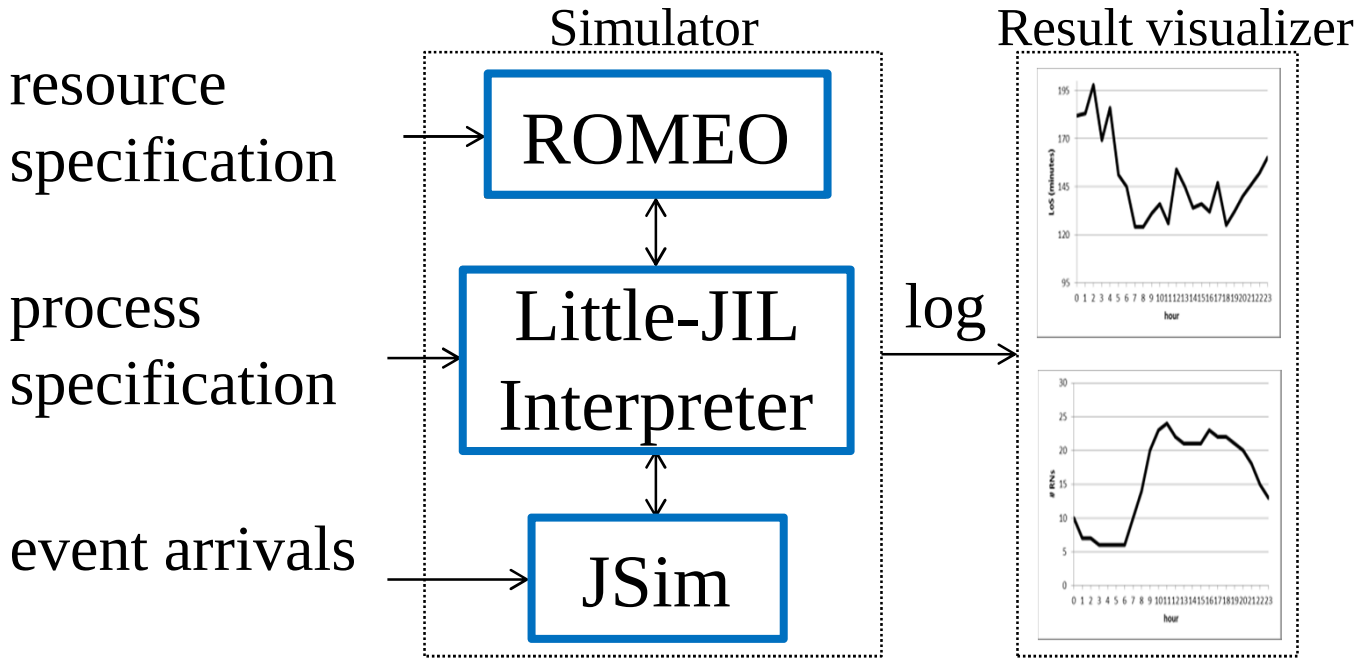


Commercial Discrete-Event Simulators

- Arena by Rockwell Automation
  - Process control flow
  - Queuing model
- SimEvents by MathWorks
  - Hybrid system
  - Discrete and continuous dynamics

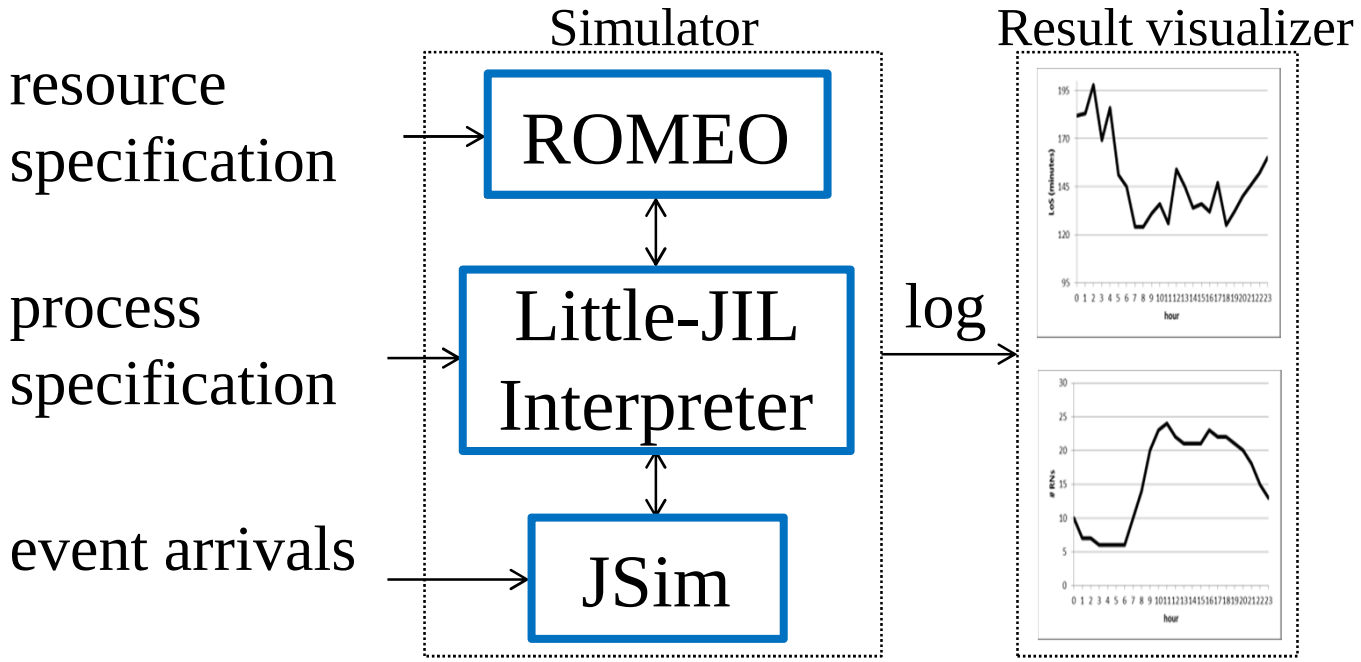
- Our Approach
  - Process model
  - Resource model

Process and Resource Models



- Separation of concerns
- Example applications
  - Software development
    - Product quality, time to market, development cost
  - Medical processes
    - Patient care quality, waiting time, net revenue

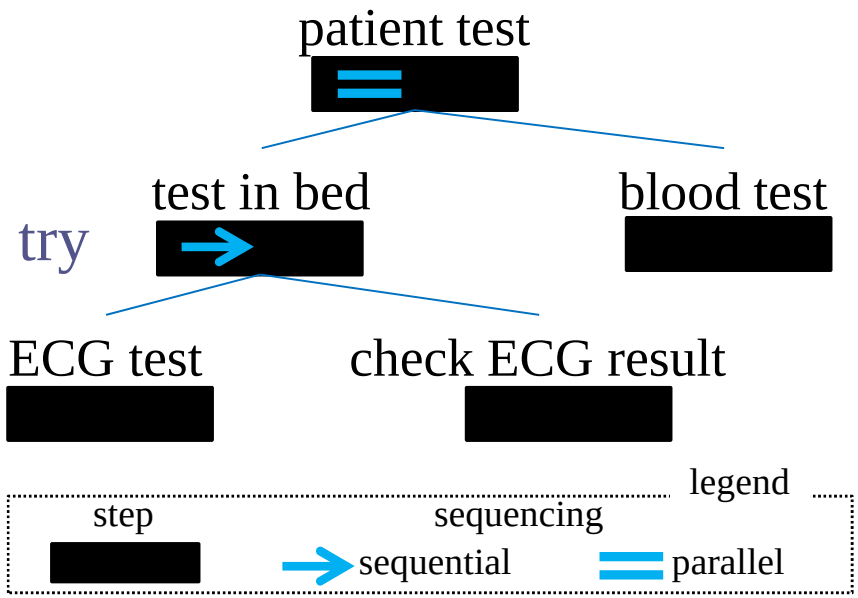
Separation of the Resource Concerns



- Decrease system description complexity
- Flexible constraints change
- Easy tracking of the resource usages

Little-JIL Language

- Rich semantics
  - Sequencing
    - sequential, parallel, choice, try
  - Exception handling
  - Pre/post requisites



- Effective in specifying resource requests
Step	Request
ECG test	RN(registered nurse), ECG
check ECG result	MD(medical doctor)

Resource Specification

- Type
  - Attributes
  - Capacity
  - Capabilities
  - Constraints
    - Availability
    - Policy
- Instance

[Resource type]
Type: medical doctor

Attributes:
name, location
Capacity:
patients
Capability:
patient care steps
Constraints:
working hours
patient care policy

[Instances]
Phil, David, John

[Instance: Phil]
Attributes:
name: Philip L. Henneman
location: main track 1st floor
Capacity: 4
Capability: check ECG result, …
Constraints:
working hours: 9AM-5PM
sickest patient first

```
<instance type="medical doctor" id="3" set_attribute="name" value="John" />
<instance type="medical doctor" id="3" set_attribute="location" value="main-track" />
<instance type="medical doctor" id="3" set_attribute="shift" value="11PM-7AM" />
```

Evaluation

- Using the simulator to answer resource-specific questions
  - Challenges in Emergency department modeling
  - Experiments

Challenges in Emergency Department Modeling

- Six acuity levels
  - Different treatment processes, protocols about priorities
- Staffing
  - Shift representation
- Same doctor, nurse constraints
  - Domain specific patient care constraint
- Fast & main tracks
  - Independent resources
- Handoff
  - Fast track closing, shift ending

Experimental Questions

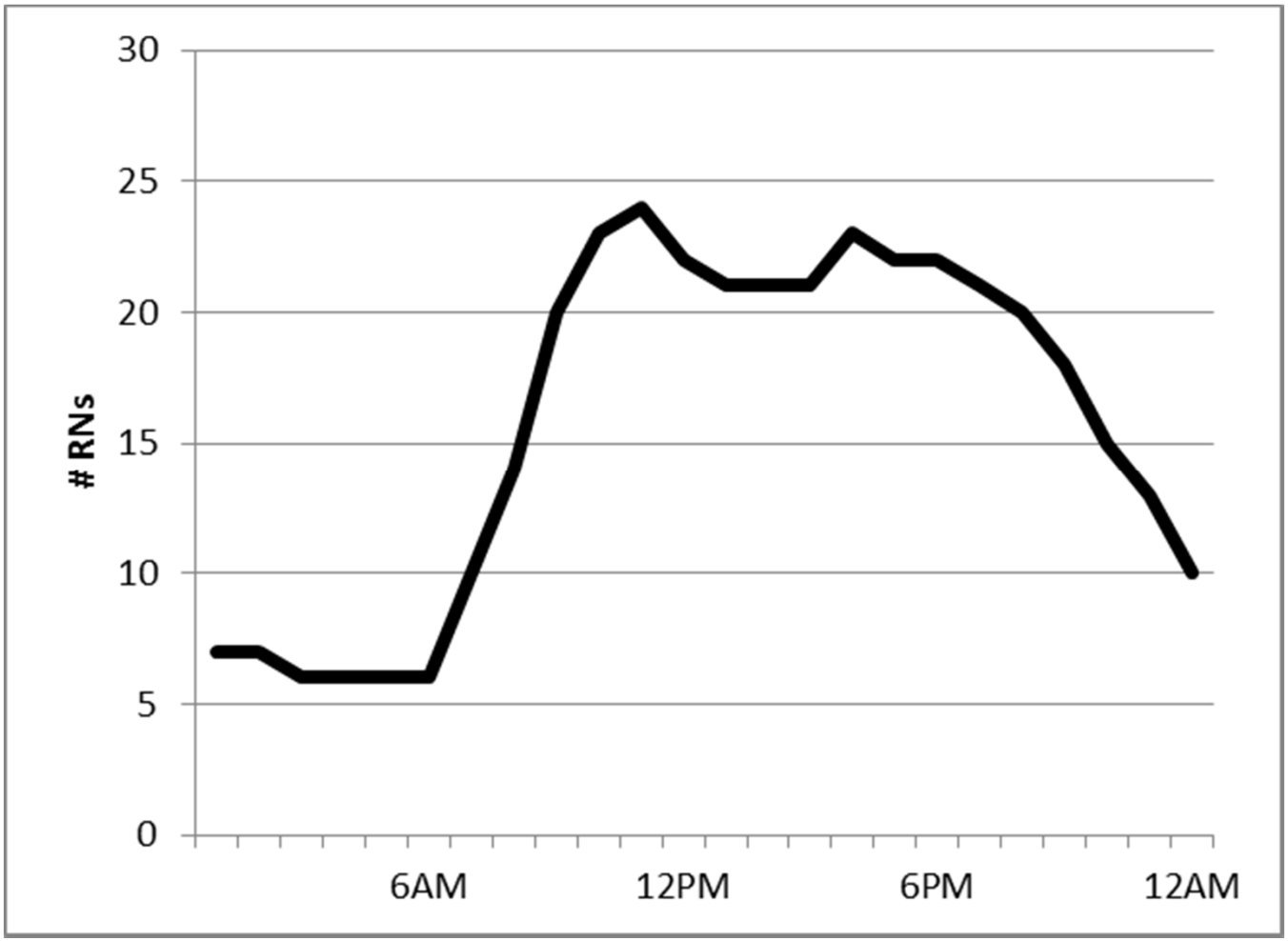
- How do we find an efficient staffing?
  - Example: registered nurse
- How do we decide the number of non-human resources?
  - Example: bed, x-ray room

How do we find an efficient staffing?

- Emergency department
  - Objective
    - manage average patient length of stay
  - How to schedule staff to satisfy the objective
- Resource-aware discrete-event simulation
  - Emergency department model
    - Baystate medical center, MA
  - Objective
    - average patient length of stay must be between 15% and 30% of the minimum
  - Design a staffing satisfying the objective
  - Analyze the effects of the staffing

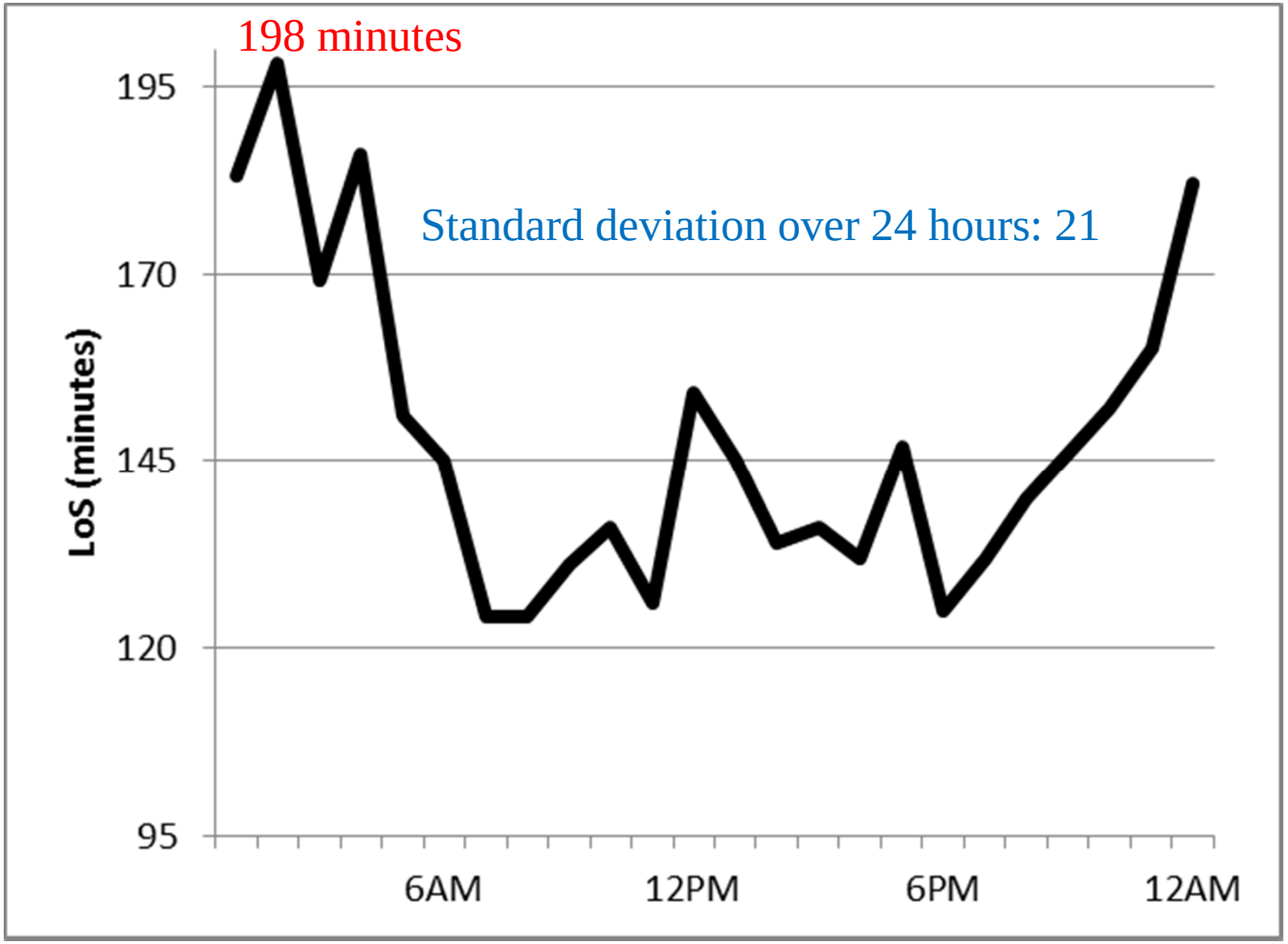
Design a staffing satisfying the objective

- Input: patient arrivals, objective function



Analyze the effects of the staffing

- Input: registered nurse staffing



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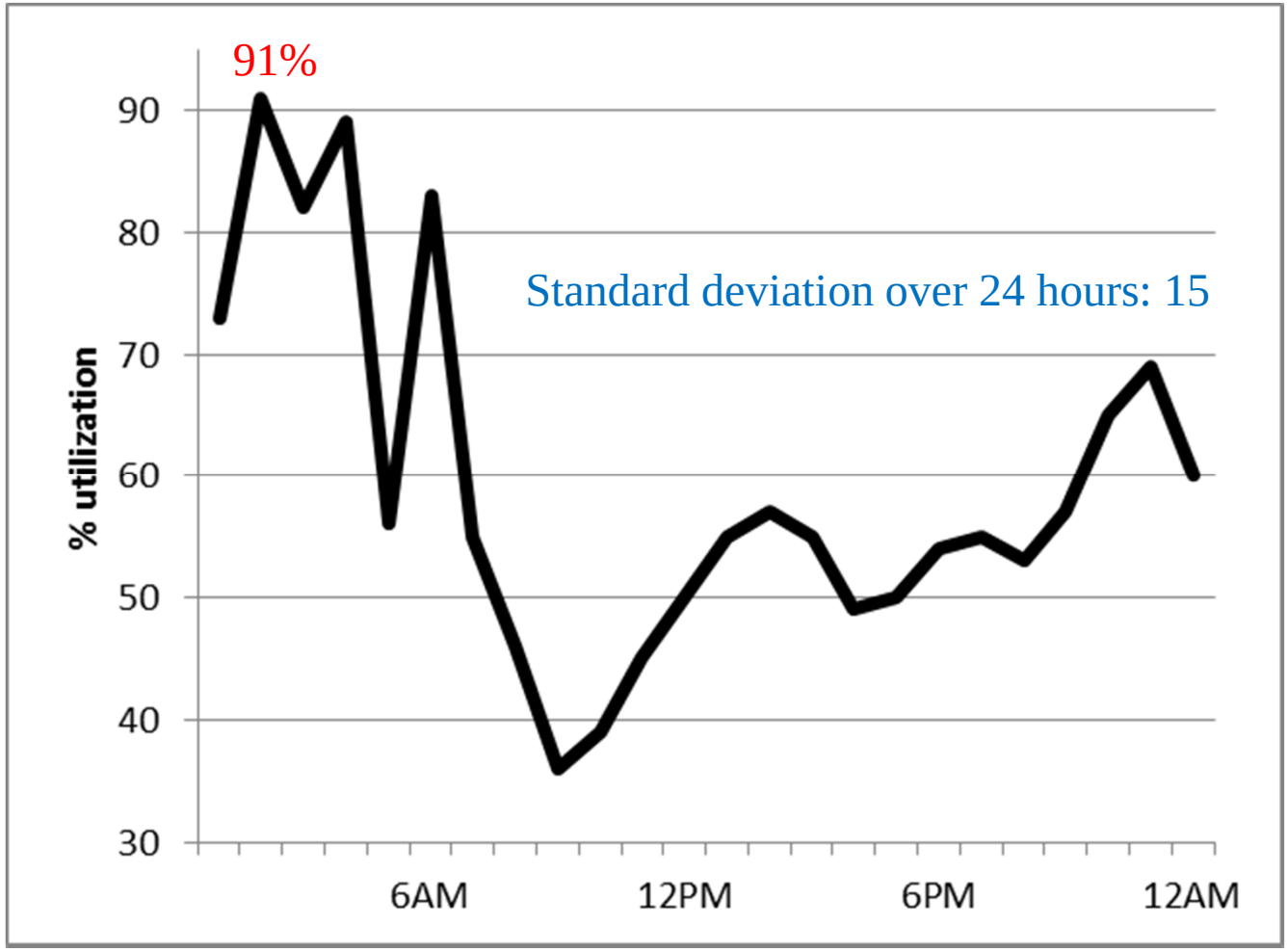
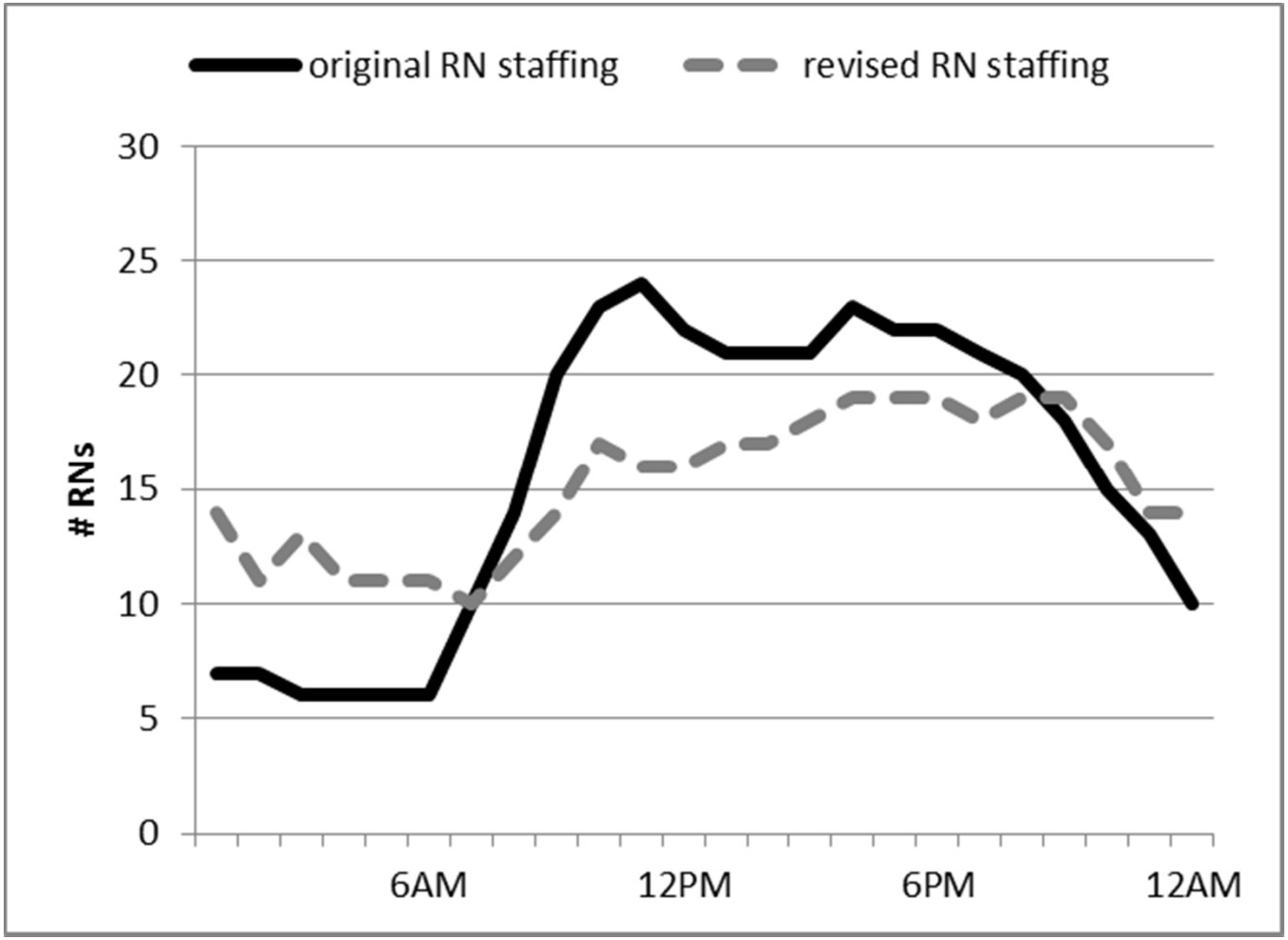


Observations about staffing results

- Satisfactory staffing for the objective function
- Unsatisfactory length of stay and utilization distributions
- Can we find a better staffing?
  - Objectives
    - Average patient length of stay must be between 15% and 30% of the minimum
    - Minimizing the standard deviation of the outputs

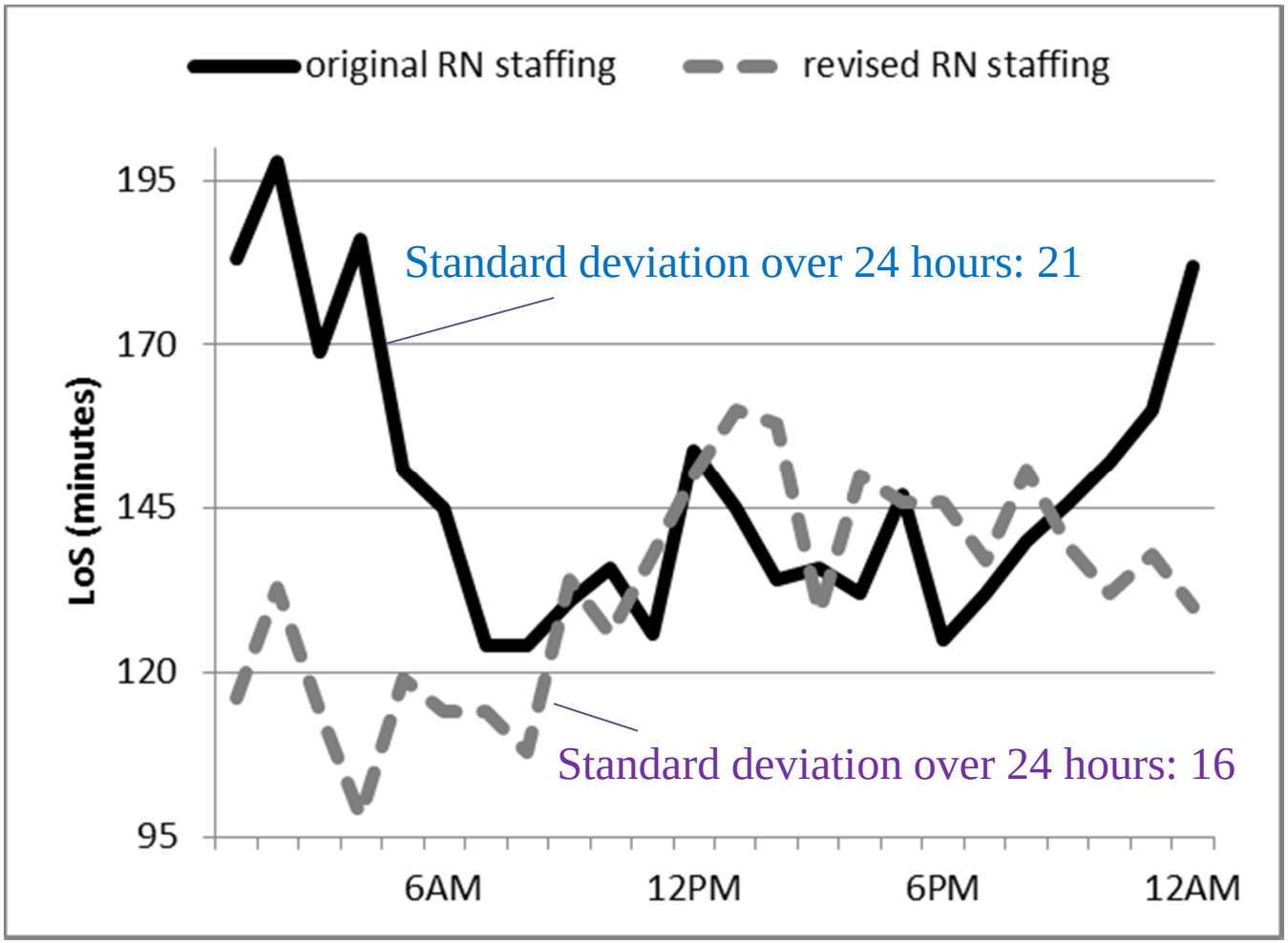
Design a staffing satisfying the objectives

- Input: patient arrivals, objectives



Analyze the effects of the staffing

- Input: registered nurse staffing



Analyze the effects of the staffing

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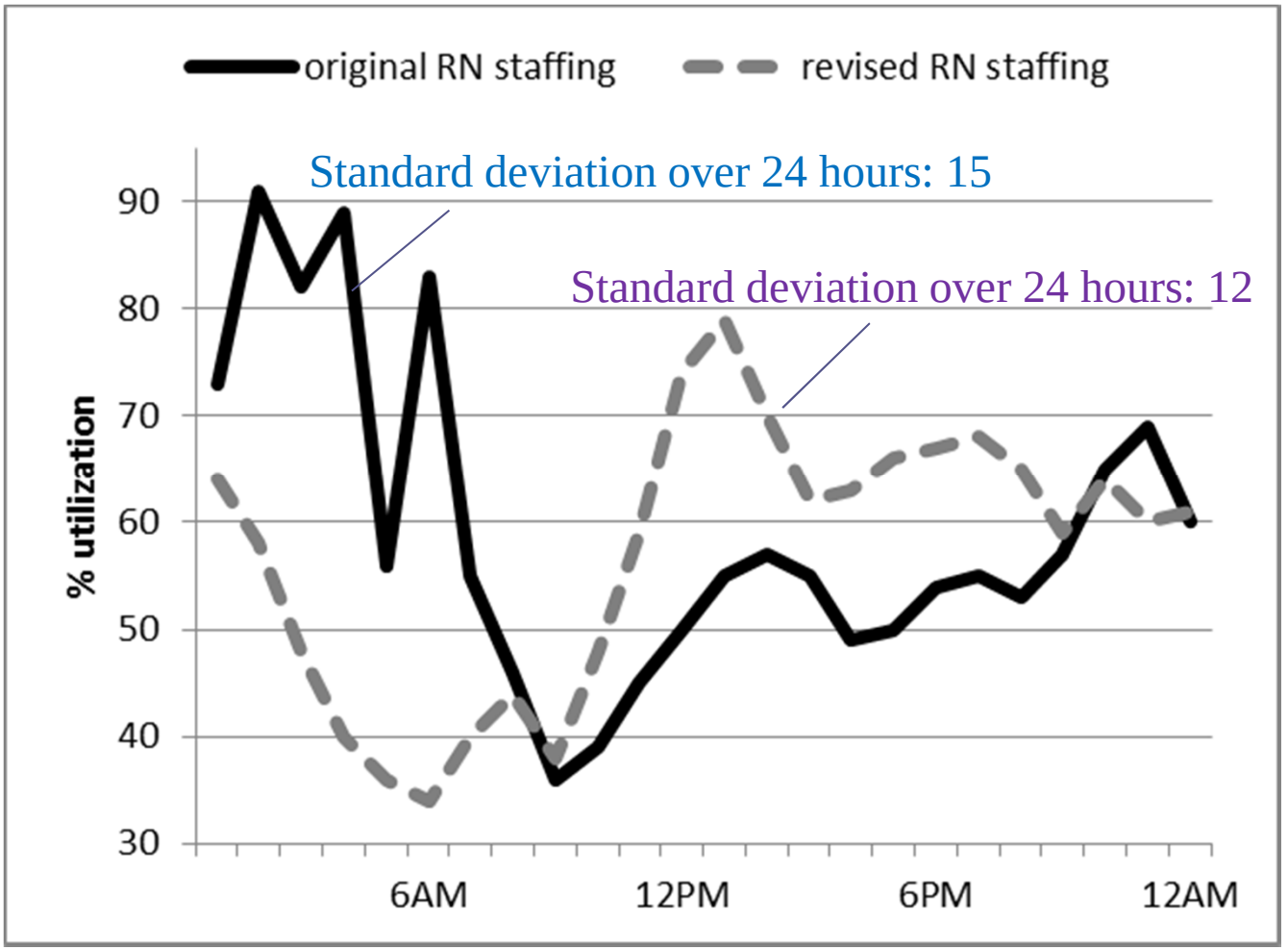
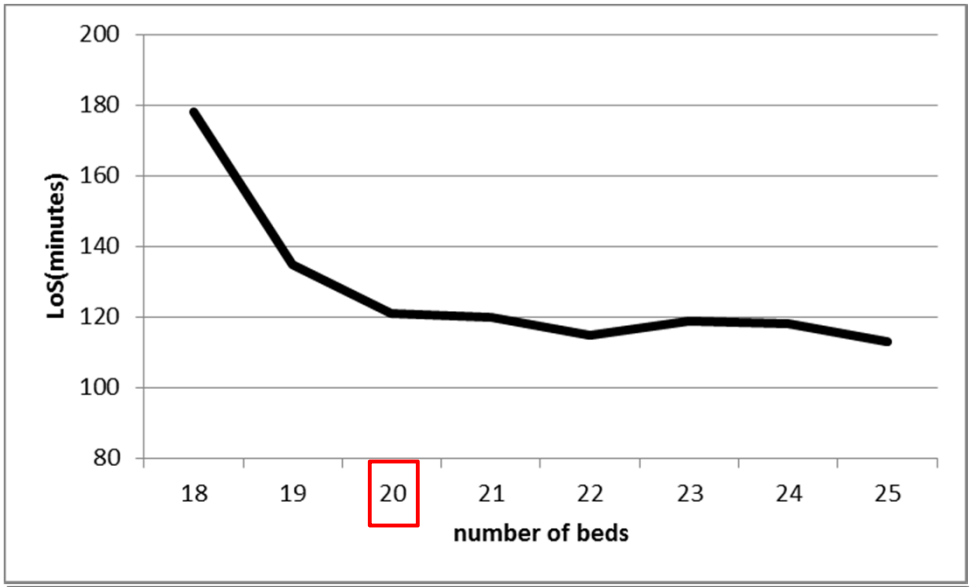


Non-Human Resource Use

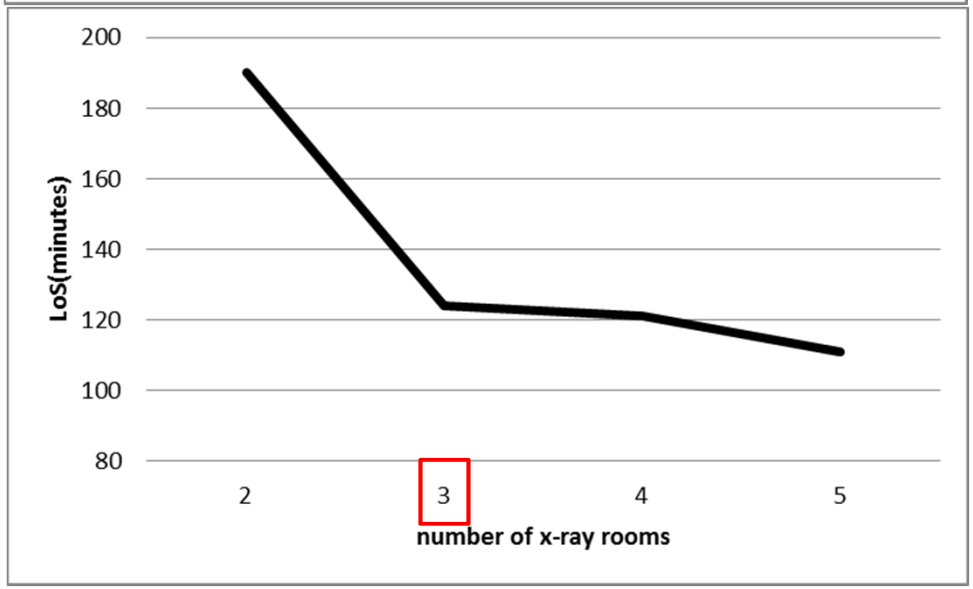
- Emergency department
  - Non-human resource management
  - Balancing patient length of stay and cost
- Resource-aware discrete-event simulation
  - Non-linear relation between length of stay and the number of resources
  - Adjust the number of beds
  - Adjust the number of x-ray rooms

Non-Human Resource Use

- Input: # beds



- Input: # x-ray rooms



Summary of Experiments

- Emergency department
  - Staffing problem
  - Complex relation between resources and processes

- Separated resource management component
  - Easy to make changes

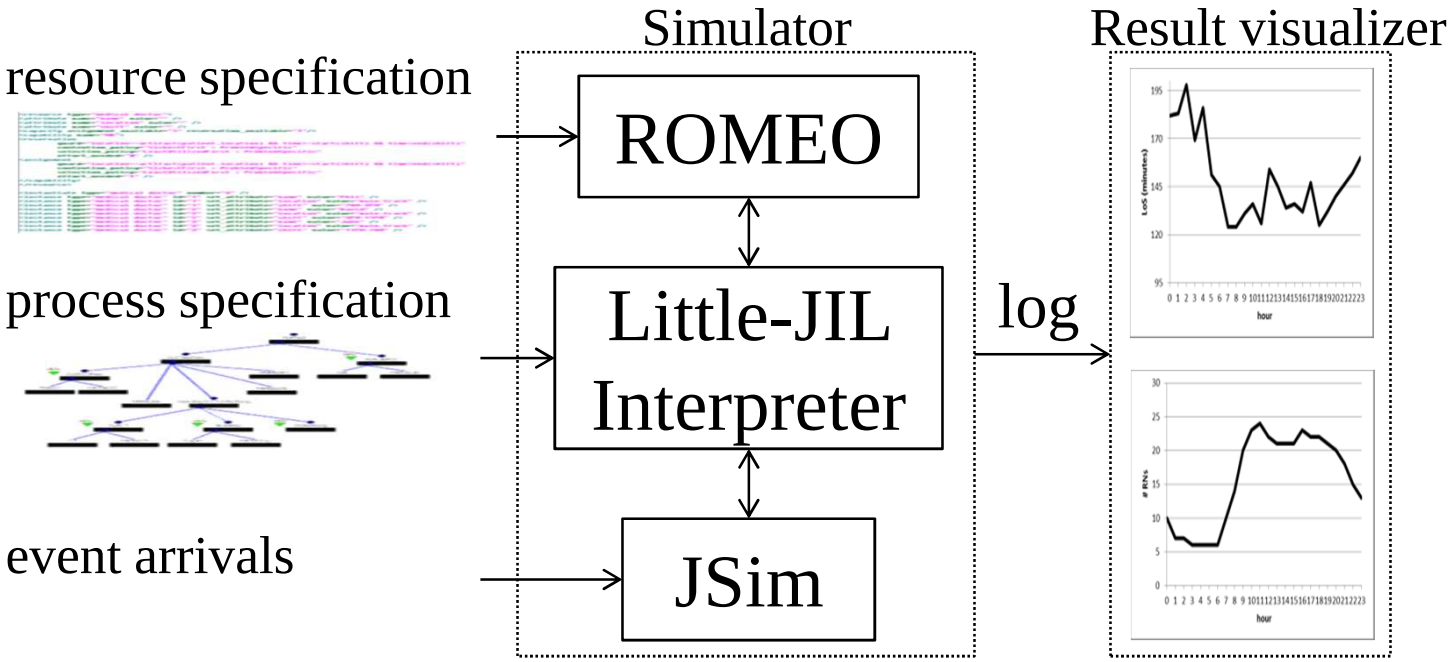
Related Work

- Approximating optimal solutions using randomized algorithms
- Staff scheduling using a queuing model based approach [Green01]
- Emergency department resource management using a discrete-event simulation [Beck09]

Future Research: Simulation Validation

- Do the simulations have real-world relevance?
  - Lack of oracles
- What properties need to be validated, and how?
  - Many properties and validation techniques
- Consistency validation among specifications
  - Different resource specifications
  - Resource specifications and other process specifications

Contributions



- Resource-aware discrete-event simulation
- Model and tool to study an emergency department
- Useful resource model for hospital administrators