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Simulation in Healthcare

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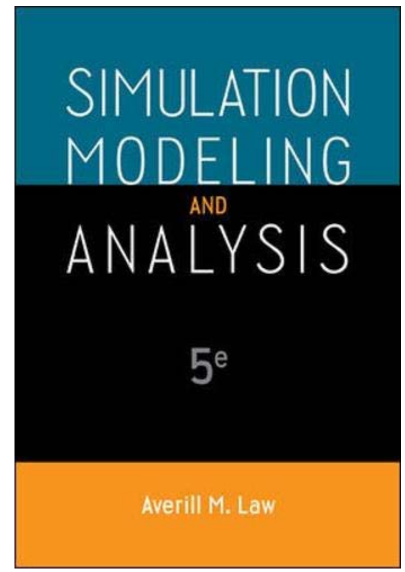
- **Recommended reading**

Averill M. Law, Simulation modeling and analysis, 5th edition



What is simulation?

- *Wikipedia:* "Imitation of the operation of a real-world process or system over time. The act of simulating something first requires that a model be developed; this model represents the key characteristics or behaviors/functions of the selected physical or abstract system or process"
- Applies in many industries and fields
- Very popular and powerful method

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What is simulation?

Simulation is a numerical technique for conducting experiments with certain types of logical or mathematical models, describing the behaviour of complex systems on a digital computer over extended periods of time

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Simulation is …

- A **numerical** technique
  - Approximate solutions: solving mathematical problems is too complex to provide analytical solutions (e.g. behaviour of nonlinear systems)
  - Queueing theory vs. Simulation
    - Queueing theory: mathematical models to simulate waiting lines
      - If demand > capacity: models for optimizing capacity (trade-off capacity cost and service time)
      - Optimization is better; but complex reality with dynamic effects and random events → seldom validly represented by analytical model due to unrealistic assumptions → simulation
- For conducting **experiments**
  - “what-if” analaysis: evaluate various strategies (within the limits imposed by a criterion or set of criteria)

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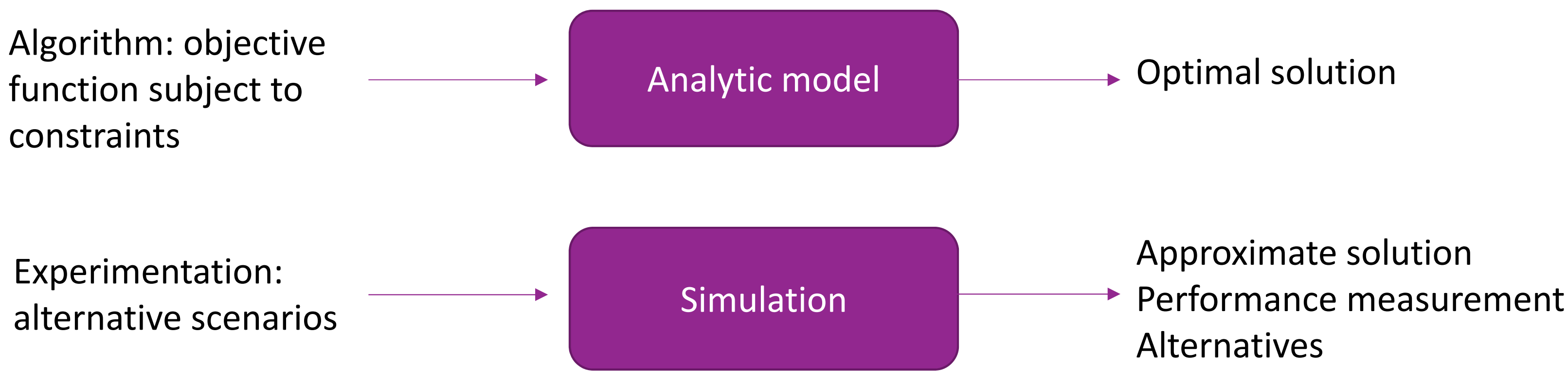
- Simulation vs. analytic models



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Simulation is …

- With certain types of logical or mathematical **models**
  - Model = set of assumptions about how the system works
  - Study behavior of model rather than real system: easy, fast, cheap, safe
    - Model validation: relationship between real system and conceptual model (building the right model?)
    - Sensitivity analysis: input parameter modifications, impact assumption violations
- Describing the behaviour of complex **systems**
  - System = actual or planned business process (e.g. warehouse, production facility, hospitals)
    - Change of system state = event (e.g. number of doctors available in ED)
  - Learn about behaviour/performance of systems: design, measure, improve and control

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Simulation is …

- On a digital **computer**
  - Computer software: Arena, Matlab, Enterprise Dynamics, AnyLogic, etc.
  - Verification: translate conceptual model to operational model in software language (building the model right?)
- Over extended periods of **time**
  - Dynamic
  - Simulation run much faster than real time
  - Reduce uncertainty of events in a time period (e.g. arrival pattern of patients)
    - Uncertainty represented by random number generator (distribution function)

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Why simulation?

Advantages

- Complexity
- System variability
- Flexibility: changes in system
- Experimentation: reporting functionality (e.g. graphs)
- Simulation speed
- Visualization power (2D/3D)
- Cost-effective
- User-friendly

Disadvantages

- Approximate solution: estimates
- Data requirements
- Validation and verification
- Time effort vs. Model accuracy (scope + level of detail)
- Learning how to simulate
- Computational feasibility

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When to use simulation?

- Analysis of business processes
  - Support decision-making by evaluating improvement strategies in a cost-effective, non-disruptive manner
  - Predict the system's performance when time evolves (dynamic)

NOT useful if:

- Simple to calculate analytically
  - No stochastic (deterministic)

Healthcare engineering solutions:

- Engineers (experimentation) vs. Doctors (evidence-based)
- Visualization power: understanding > awareness > commitment > impact

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Types of simulation

- Deterministic vs. Stochastic
  - Predictable system
  - Statistical distribution functions
- Discrete vs. Continuous
  - Event-based: change of system state at given points in time
  - State variables change every moment
- Static vs. Dynamic
  - Time independent decisions
  - Time dependent decisions

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Types of simulation

	Monte Carlo/ Markov queueing	Discrete-Event simulation	System Dynamics	Agent-based simulation
Static / Dynamic	S	D	D	D
Discrete / Continuous	D	D	C	C
Deterministic / Stochastic	S	S	D	S

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Types of simulation

Monte Carlo simulation

- Mathematical technique:
  - Randomly generate inputs from probability distribution
  - No time dimension
- Example:
  - Patient arrival time and service duration are determined by flipping a coin (heads = 1 patient arrives in an hour/2 hours service time; tails = no patient arrives in an hour/1 hour service time)

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Time interval	Patient arrival	Queue	Service duration	Doctor consultation	Patient departure
8:00 – 8:59	Heads: #1	/	Heads	#1	/
9:00 – 9:59	Heads: #2	#2	Tails	#1	#1
10:00 – 10:59	Heads: #3	#3	Tails	#2	#2
11:00 – 11:59	Tails: /	/	/	#3	#3
12:00 – 12:59	Heads: #4	/	Heads	#4	/
13:00 – 13:59	Heads: #5	#5	Heads	#4	#4
14:00 – 14:59	Tails: /	/	/	#5	/
15:00 – 15:59	Heads: #6	#6	Tails	#5	#5
		Total waiting time	**Total service time**		**Total time in system**
		4	9		2+2+2+2+3+2=13

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Types of simulation

Discrete-event simulation

- Model series of events over time (no change in system between events) = system state
  - Event list + event controller (simulator)
- Simulation components:
  - Entities move around, change status
  - Resources assigned to entities (entities competer for people, equipment, space)
  - Attributes (global/local characteristics of model/entities: parts in system, color/priority)
  - Queues
  - Statistical counters: measure performance indicators (waiting time, utilization rate, etc.)
- Micro-modelling (low abstraction level): operational and tactical decision-making

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Process (service time)

Output performance measures (time finished)

Queue

Entity creation (arrival time)

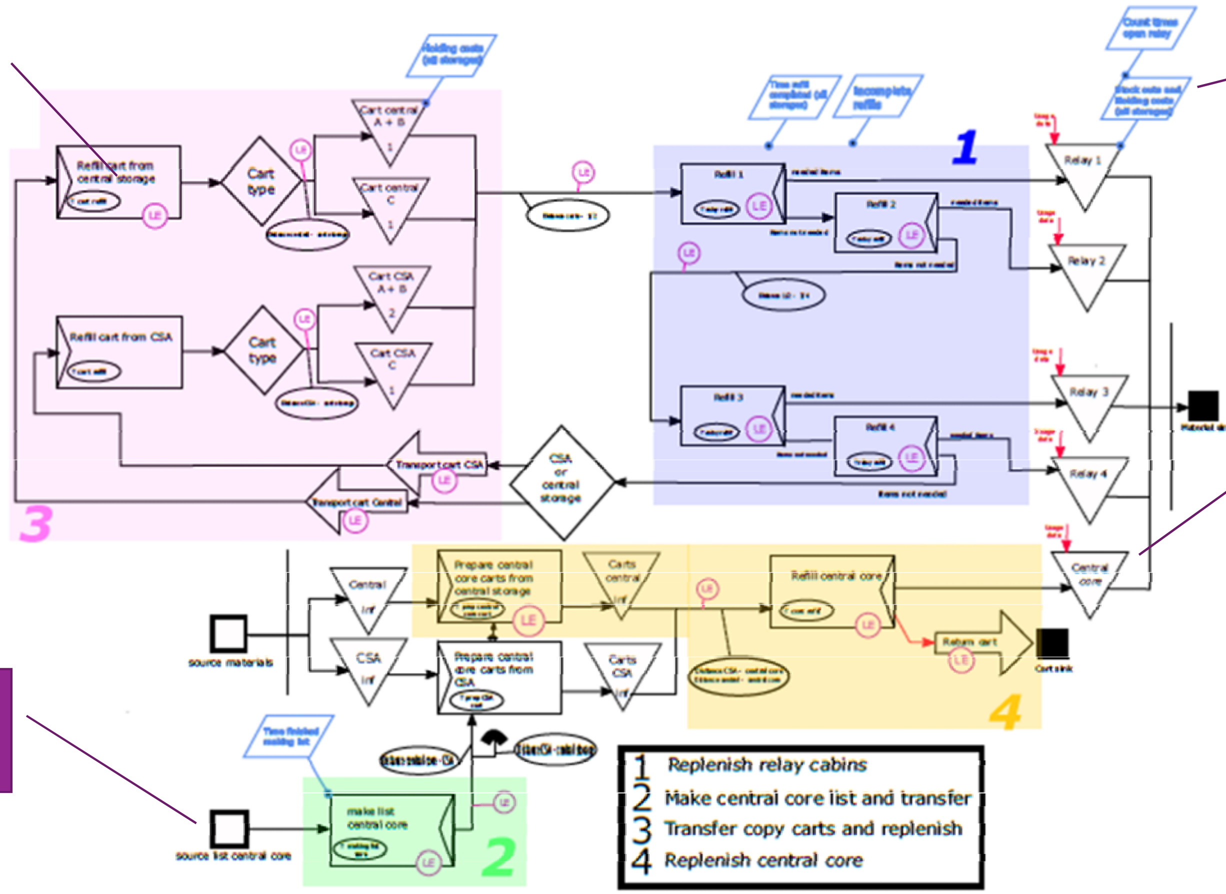

Figure 4.7: As-is scenario conceptual model

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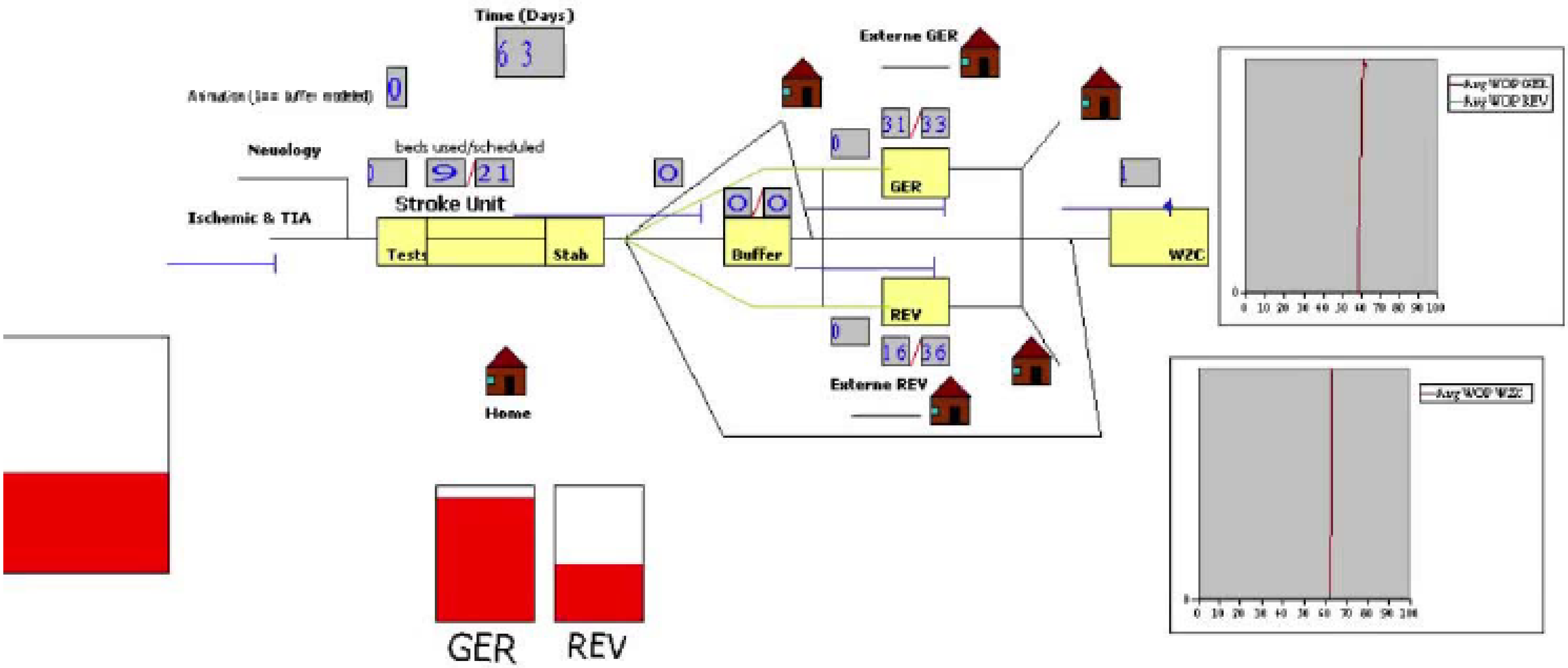

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Types of simulation

System dynamics

- Abstract macro-modeling for strategic decision-making
  - Aggregate level vs. individual objects (DES)
  - Relationship between system elements using feedback loops
    - Stocks = state variables
    - Flow = rate (change value of stocks)
    - Loop when changes in a stock affect flows in/out the stock

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Types of simulation

Agent-based simulation

- Modeling of operations and interactions of autonomous agents to evaluate impact on system
  - Agent = active, autonomous entity with own goals and behaviours
  - System = interacting agents
    → No controller for how system operates

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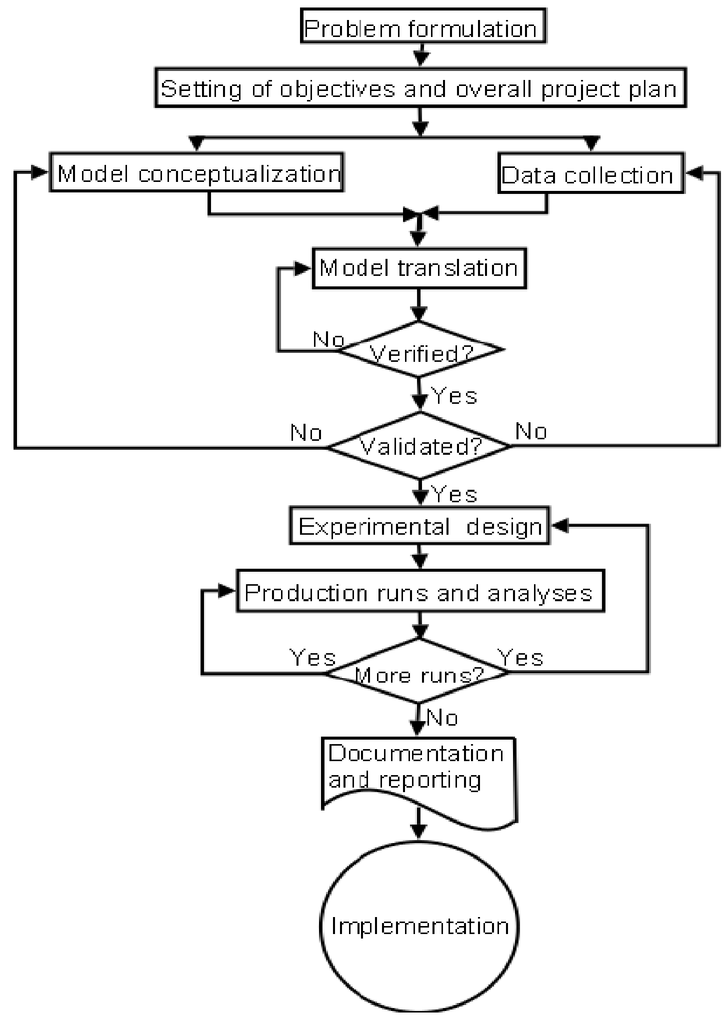
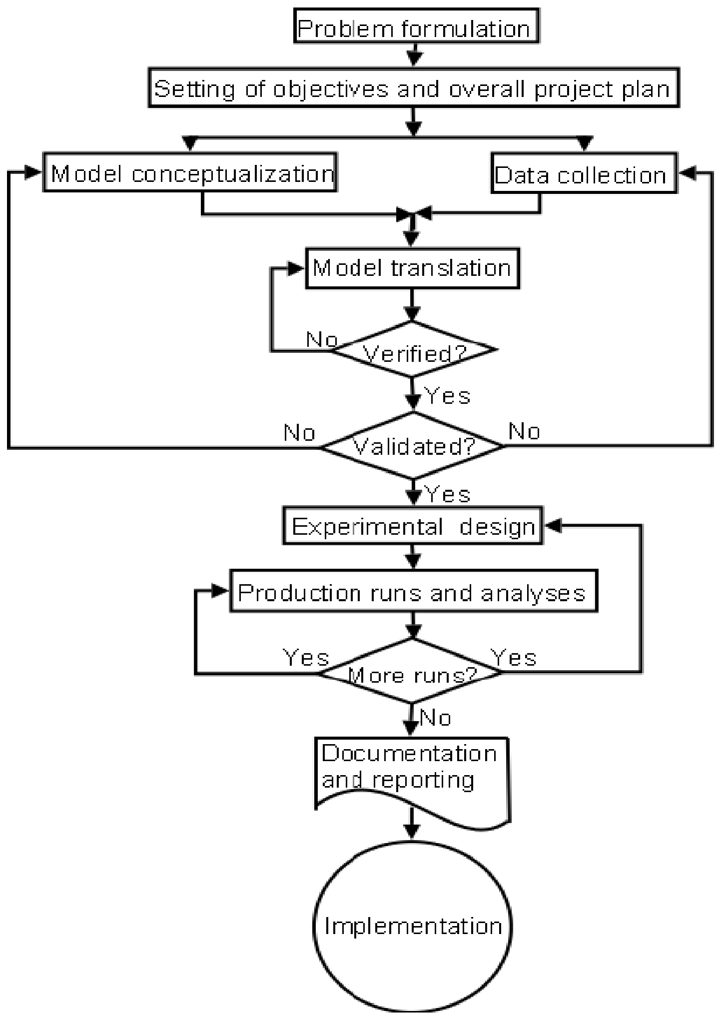
Simulation study roadmap

- Problem definition
  - Understand problem situation
- Conceptual model (blueprint):
  - Scope (what to model?): modeling objectives, resources, input, output
  - Level of detail (how to model?): assumptions, simplifications
  - Data requirements
  - Object flow diagram: model constructs



Simulation study roadmap

- Model translation:
  - Computer-specific software
  - Verification and validation
    - Build the model right: debugging
    - Build the right model: sensitivity analysis
- Experimental design
  - Scenario analysis
- Replication
  - The more runs, the more accurate the performance measures
  - Confidence intervals, statistical t-test
- Reporting: analyze ouput data
- Implementation



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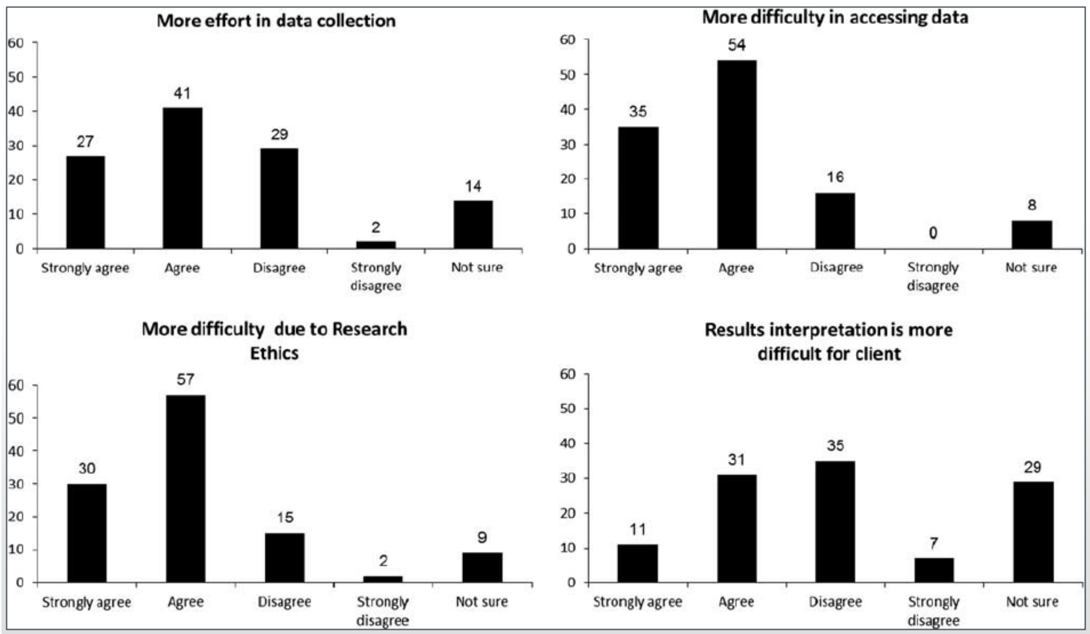
Simulation in healthcare

- Modeling healthcare systems is more difficult than in other sectors



Tako and Robinson (2015). Is simulation in health different? Journal of the Operational Research Society, 66, 602-614,

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Simulation as a tool to support healthcare decision making

- Successful application in manufacturing and business application, but rather novel in healthcare sector
- Healthcare organizations are subject to economic constraints and service-based targets → Improve operational efficiency while maintaining quality of care
- DES as supporting tool for decision makers
  - Define operations, map processes and gathering data in structured way to understand current situation and identify improvement opportunities
  - Stimulate stakeholder commitment: trust in findings and ensure objective, data-driven decision-making
- Lack of implementation of results
  - As-Is vs To-Be comparison highlights importance of pairing DES with monitoring KPIs of improvement strategies
  - DES is a valuable tool to target operational improvement actions by managing variability associated with workflows

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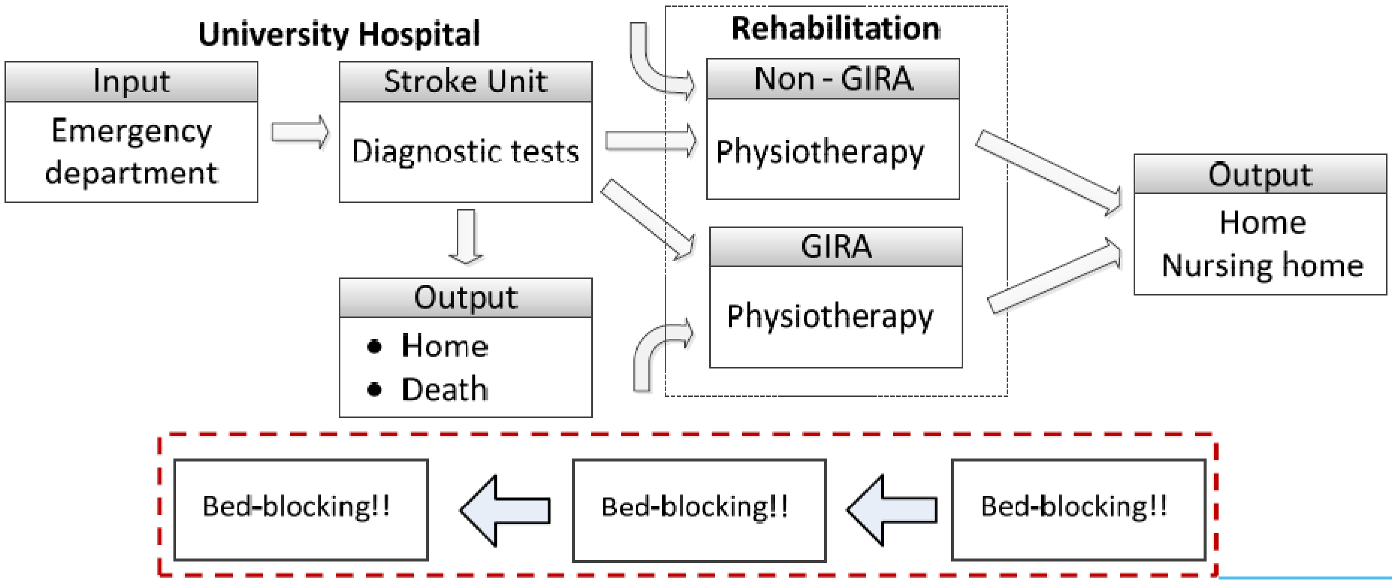
Case studies – Patient logistics

Simulation modeling for stroke patient flow

- Bed-blocking problem ➔ patient occupies bed resource though medically ready



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- Challenges:
  - Bed-blocking increases patient waiting times for stroke treatment and rehabilitations
    ➔ Diminished quality of healthcare
  - Inefficient resource allocation/optimization with the integrated stroke patient care pathway
    ➔ Balancing resources (e.g. MRI, CT scan, neurologist, nursing, etc.) with patient demand not straightforward

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- Simulation roadmap
  1. Map patient transfer process and resources along care pathway
     - Mapping tools: interview, brainstorming, patient records, observation, etc.
  2. Data requirements
     - Patient flow statistics: patient arrivals per time, number of treatment sessions, patient waiting time, number of doctors, etc.
       → Distribution functions
  3. Assumptions
     - Transportation means available when required
  4. Simulation model
     - Patient arrival > diagnosis/treatment > transfer to rehabilitation center > rehabilitation > patient discharge

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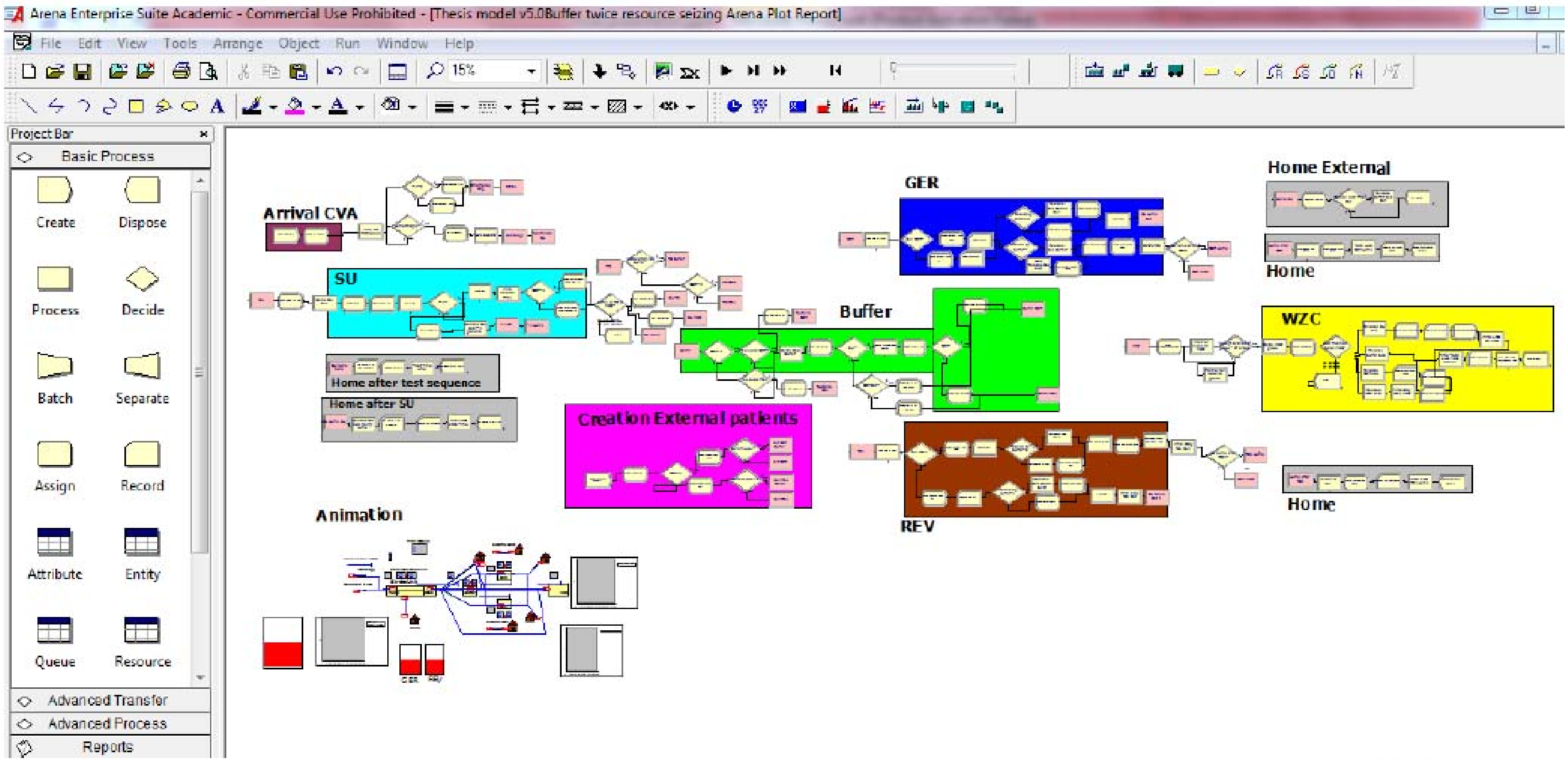

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5. Model validation
   - Comparison with patient data
6. Experimentation
   - Evaluate alternative improvement scenarios: determine optimal bed size to minimize patient length of stay

     →Unlimited bed capacity:

     →Varying transfer schedule

     →Vary age limit to geriatric ward

     →Implement shared ward

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Case studies – Materials logistics

Simulation modeling of surgical case cart distribution flow

1. Variability in workflows between operating room clusters and reduce waste
2. Data: picking time, traveling time, items per case cart
3. Case carts assumed to be available when required
4. Simulation model

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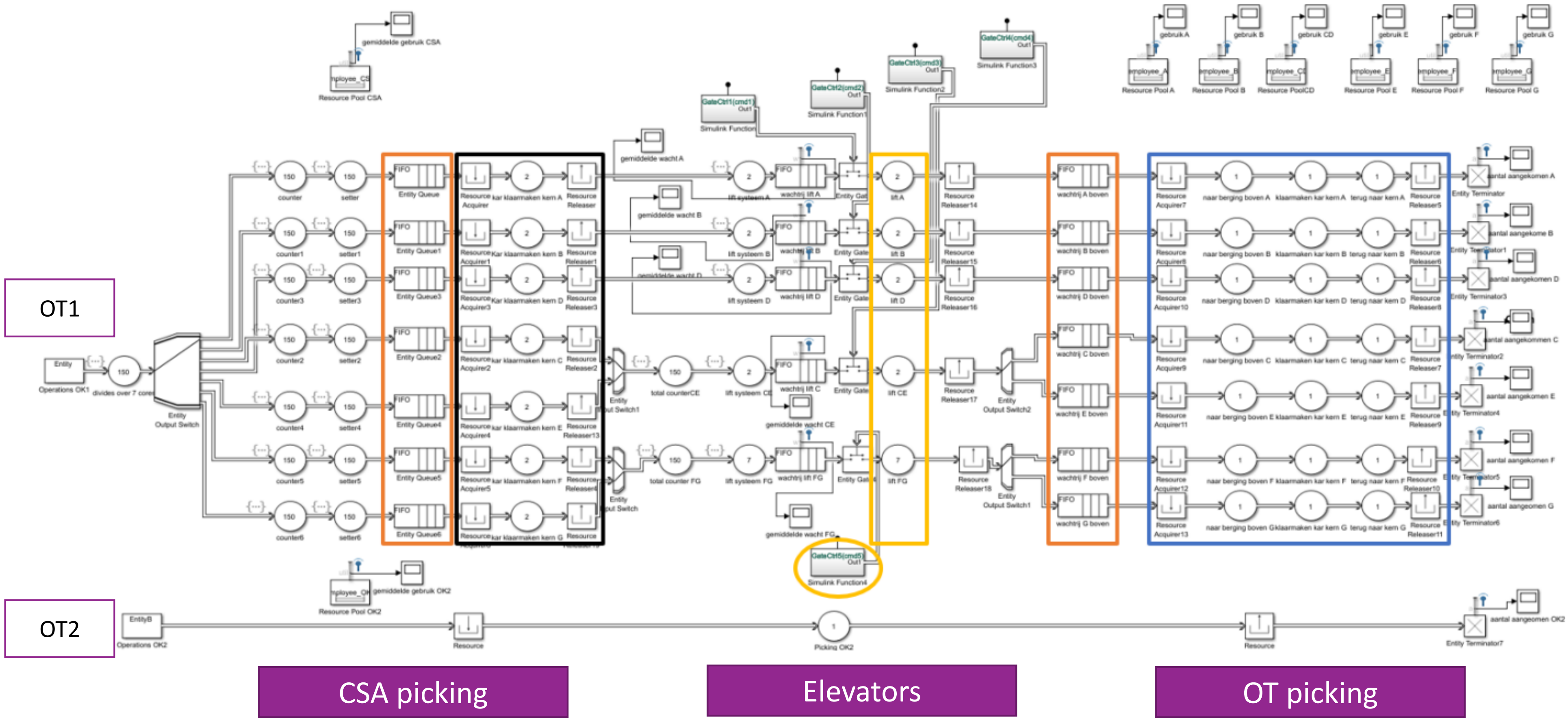
HELP – Healthcare Logistics Education and Learning Pathway



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5. Debugging, use expert opinions (practical experience), structured walkthrough, run simplified model (predictable), observe animation
6. Experimentation:
   - Impact of standardization: streamline workflows
   - Impact of centralization: reduce logistics movements close to operating room
   - Impact of elevator: reduce idle time

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Questions?

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