Data, Decision-making, and Building Decision Support Systems

A Technologist's Perspective

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Massachusetts Institute of Technology - Lincoln Laboratory

Mission: *"Technology in Support of National Security"*

MIT Lincoln Laboratory
(Lexington, MA)

~15 miles

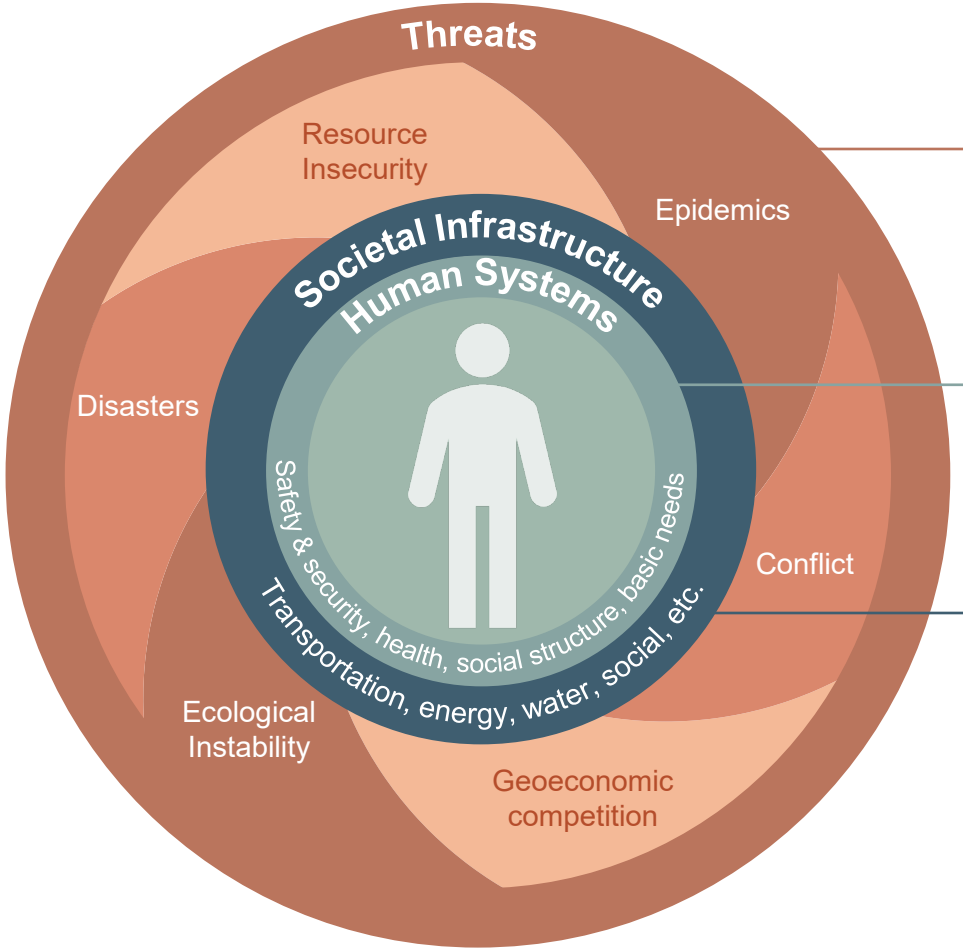
MIT Main Campus
(Cambridge, MA)

Key Roles

- Gap & architecture analysis
- Enabling technology development
- System prototyping & evaluation

Human Resilience Technology Group

Improving human resilience through the application of science and engineering to enduring national security challenges



Environmental Threats
- Assess impacts
- Model interactions

Societal Infrastructure
- Architect solutions
- Build technologies

Human Systems
- Define requirements
- Quantify outcomes

Mission, Approach, & Goals

- **Develop sensors, analytics, and decision support software to build technologies and systems that improve human resilience**
- **Work closely with local, state, and federal agencies to develop these technologies**
- **Enable organizations to more effectively gain situational awareness, share information, and make decisions in times of crisis**

A "Decision Support System" Exemplar:
The NDMS Dynamics Model

National Disaster Medical System

…is a complex interagency construct to provide surge health care response in a mass-casualty event:

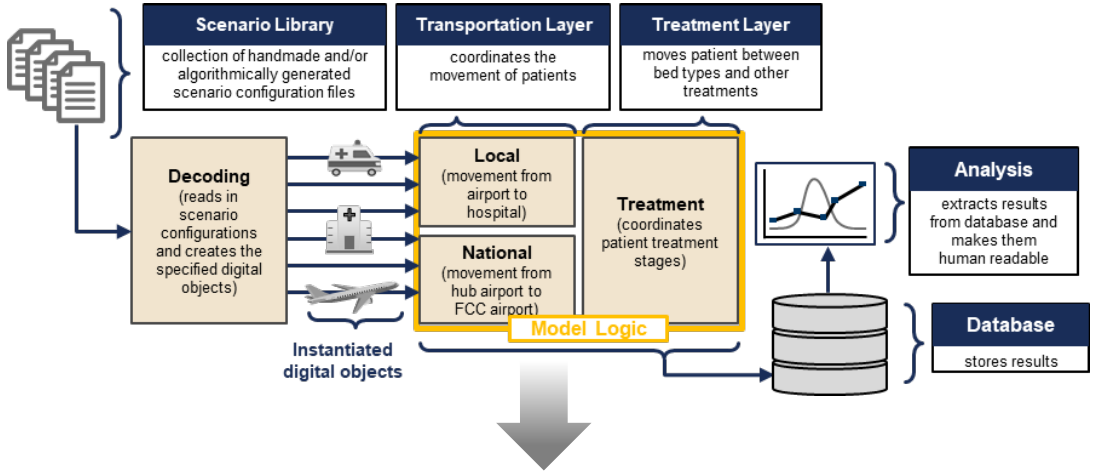
Large-scale Disasters or Combat Operations → Nationwide Resource Pool

- Air and ground transport
- DoD, VA, and civilian hospitals
- Specialty beds and staffing

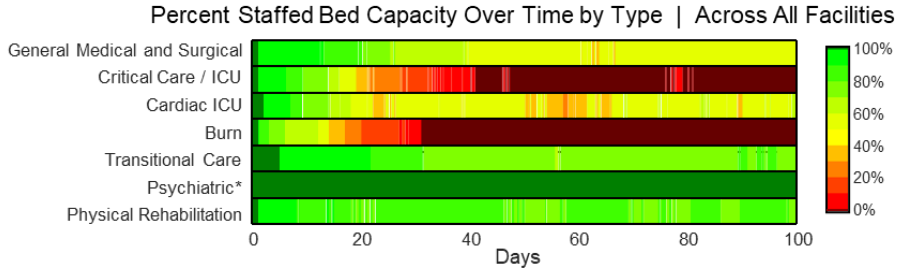
- **The NDMS has never been challenged at scale**
- **Major concerns about its unknown performance limits:**
  - Unprecedented casualty numbers, injury types, and severity
  - Inadequate or unpredictable staffed bed availability
  - Inadequate transport assets and uncertain destinations for wounded
  - Civilian hospitals already operate near capacity
  - No existing comprehensive assessment of true NDMS capacity, fragility, or candidate improvement approaches

MIT LL NDMS "Simulation Engine"

MIT Lincoln Laboratory has created a new system-scale model of the NDMS with unprecedented granularity and quantitative rigor:



…and are actively supporting NDMS structural and policy improvements through quantitative scenario analysis:



FCC: Federal Coordination Center

1. Start with the Decision

“If you don't know what decision you are trying to make, you have no business looking at data. Data science is only useful when it’s actionable, and action requires a choice.

You must design your system backward from the decision boundary, not forward from the database.”

- Cassie Kozyrkov

Capability Goals:

1. **Identify areas of NDMS fragility and prioritize strategic resource investments**
2. **Assess benefits of structural change through policy**
3. **Guide tactical decision-making during a mass casualty event**

We needed to break these high-level goals down in to concrete, actionable objectives capable of being modeled

Motivating Questions

System Robustness

Treatment Asset Limits

- Quantify major bottlenecks in clinical staff, bed space, and specialty equipment
- Identify how long until bottlenecks might occur

Transport Asset Limits

- Locate bottlenecks on transport
- Find when they are reached

Partner Asset Limits

- Are there sufficient partner agreements to provide the necessary care?

Strategic Improvements

Policy Assessment

- Anticipate risks of staff, beds, and equipment assignment prioritization on patient outcomes
- Evaluate policies affecting staff and bed usage

Structural Improvements

- Find most beneficial areas for expansion and investment

Real-time Guidance

Patient Distribution

- Provide real-time assessment of how arriving patients should be apportioned across FCCs during a mass casualty event
- Give recommendations about which hospital a patient should be sent to

Staff Movement

- Explore effects of general and specialized staff assignment

An Iterative Development Process

Data-driven modeling approach utilizes two-way feedback between stakeholders and modelers

NDMS Stakeholder and SME Engagements

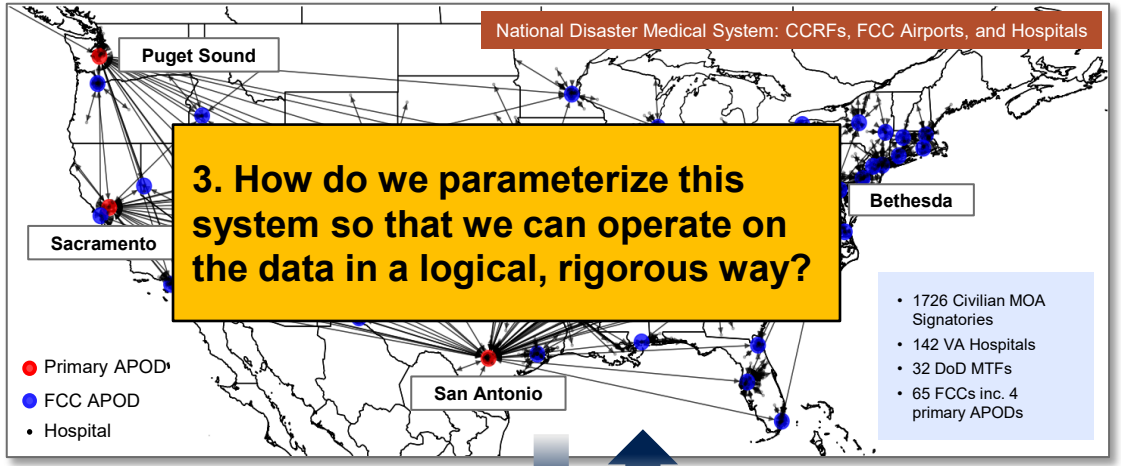
Field Observations and Operations Research

2. Who is responsible for understanding these answers, and who owns the right data? Does the right data exist?

- System Description
- CONOPS
- Policy
- Available Data

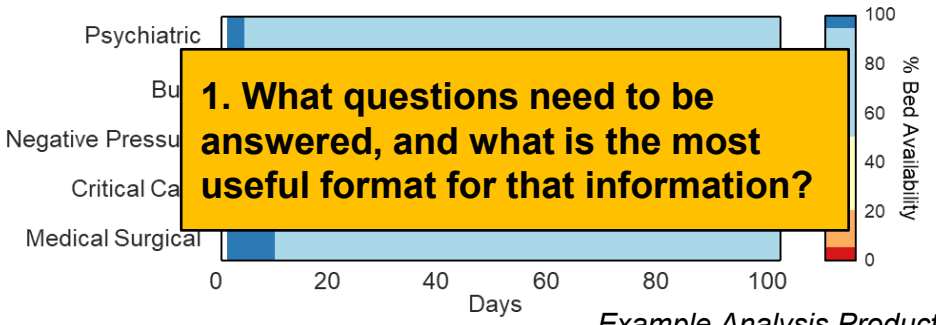
- Additional Data Needs
- Modeling Assumptions
- Analysis Results

NDMS Systems Analysis: Parameterization and Data Aggregation



3. How do we parameterize this system so that we can operate on the data in a logical, rigorous way?

Dynamics Model: Design, Build, Analyze



1. What questions need to be answered, and what is the most useful format for that information?

Example Analysis Product

MOA: Memorandum of Agreement, pertains to hospitals formally participating in NDMS
DoD: includes numerous components and CCMDs
APOD: Aerial Port of Debarkation

FCC: Federal Coordinating Center
CCRF: Combat Casualty Reception Facility
ICU: Intensive Care Unit

2. Garbage In, Garbage Out

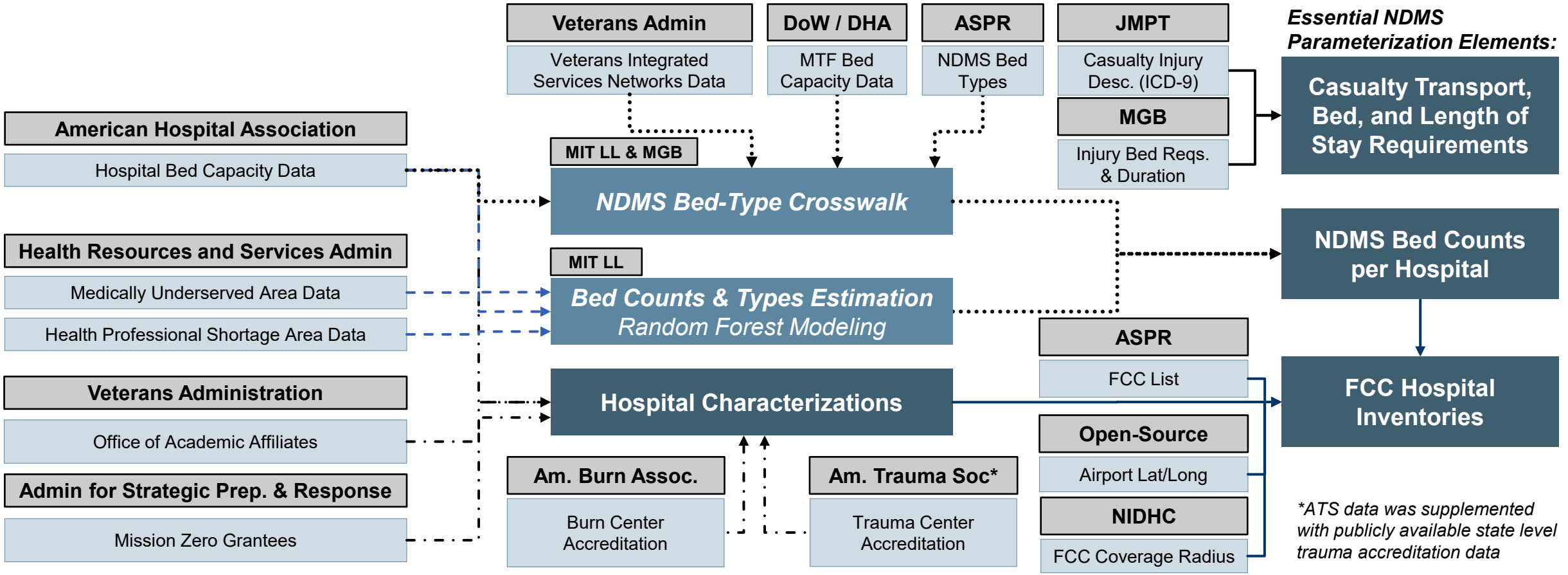
“On two occasions I have been asked 'Pray, Mr. Babbage, if you put into the machine wrong figures, will the right answers come out?’

I am not able rightly to apprehend the kind of confusion of ideas that could provoke such a question.”

- Charles Babbage

Medical Treatment: Constructing the Dataset

Accurate medical treatment requirement and available capacity estimation requires a complex set of data



MIT LL has assembled the most complete NDMS bed, casualty arrival, and treatment dataset in existence

MTF: Medical Treatment Facility
JMPT: Joint Medical Planning Tool

MGB: Mass General Brigham
FCC: Federal Coordinating Center

NIDHC: National Institute for Defense Health Cooperation

3. Think Algorithmically

"Remember that the first rule of system dynamics is that you cannot navigate a system unless you have mapped it beforehand.“

– Donella Meadows

“The main point is that computational thinking provides a framework that makes things more transparent and easier to understand.

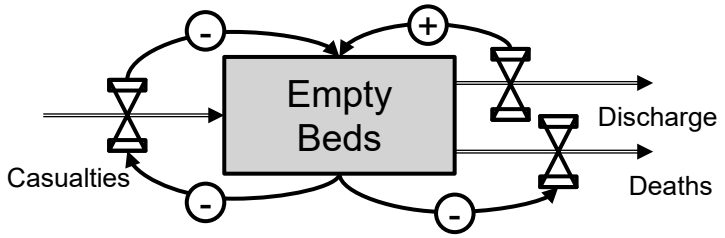
When you formulate something computationally, everyone can try it out and explicitly see how it works.”

- Stephen Wolfram

Candidate Modeling Methods

System Dynamics

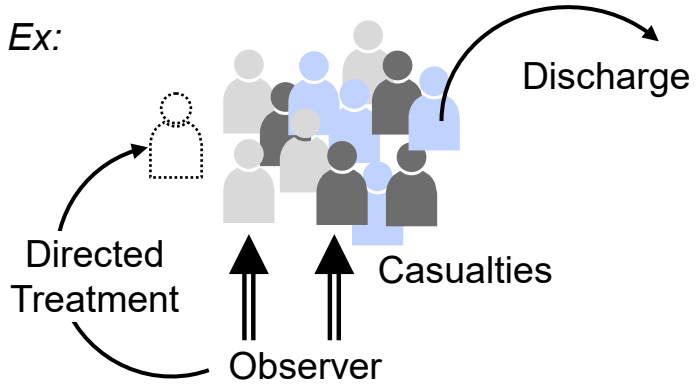
Ex:



- Considers generalized interactions between "stocks and flows"
- Treats individuals or things as undifferentiated and interchangeable
- May have a closed form solution and typically very fast to run

Discrete Event Simulation

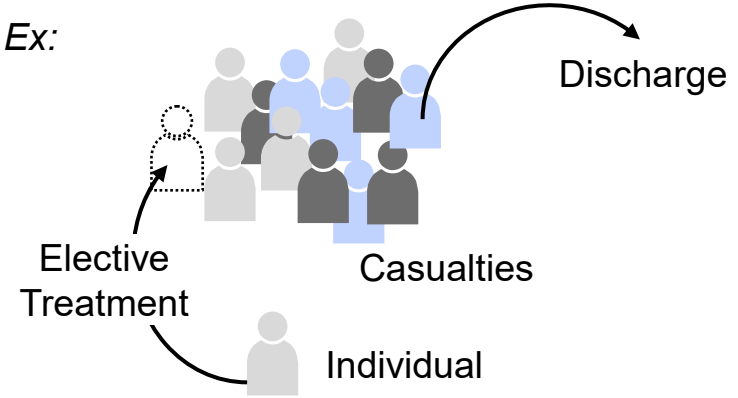
Ex:



- System rules are specific and defined
- Individuals can have their own specific properties and characteristics
- System directs entity movements based on these properties and environment conditions
- Movements are repeatable and explainable
- System model can be easily modified
- Increased computation requirement

Agent-Based Model

Ex:



- Individuals make self-directed decisions based on their own properties and environment conditions
- Can model very complex behavior
- Can result in unexpected and unpredictable outcomes
- Highest computational load (very slow)

NDMS Dynamics Model utilizes Discrete Event Simulation for its granularity, clarity, and reconfigurability

4. Build It Before You Need It

“The more you sweat in peace, the less you bleed in war.”

– Norman Schwarzkopf

“An ounce of prevention is worth a pound of cure.”

- Mothers worldwide…

Example Analysis Goals

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- **Building this decision support capability for 'enduring improvement' use makes us significantly more prepared for situational awareness in an emergency**
- **Investments made under everyday circumstances, if properly thought through, can dramatically alter the course of crisis response.**

So…

design your system backward from the decision boundary, not forward from the database	→	***Start with the Decision***
if you put into the machine wrong figures, will the right answers come out?'	→	***Garbage in, garbage out***
you cannot navigate a system unless you have mapped it beforehand	→	***Think algorithmically***
the more you sweat in peace, the less you bleed in war	→	***Build it before you need it***