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Disaster Response Applications Using Agent-Based Modeling

AnyLogic Conference 2013

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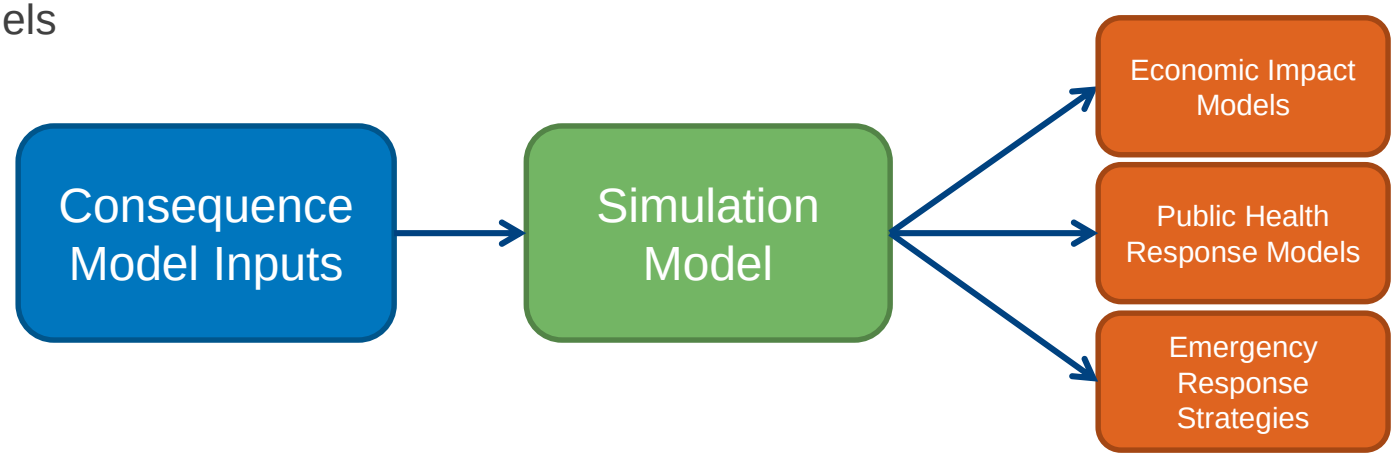
- The world's largest non-profit independent R&D organizations ($5.6 billion in revenues)
- Worldwide leader in development, commercialization, and transfer of technology
- Contract research with nearly 1,100 firms annually
- Battelle manages or co-manages seven national labs for the U.S. Department of Energy and the U.S. Department of Homeland Security, and one international nuclear laboratory in the United Kingdom
- More than 20,000 employees in more than 130 cities worldwide
- Simulation applications using AnyLogic across wide range of areas:
  - Health Care – Provider Resource Management, Clinical Workflow Modeling, Infection Control
  - Economic Development and Industry Cluster Forecasting
  - Vehicle Fleet Logistics and Maintenance
  - National Security & Disaster Response

Overview

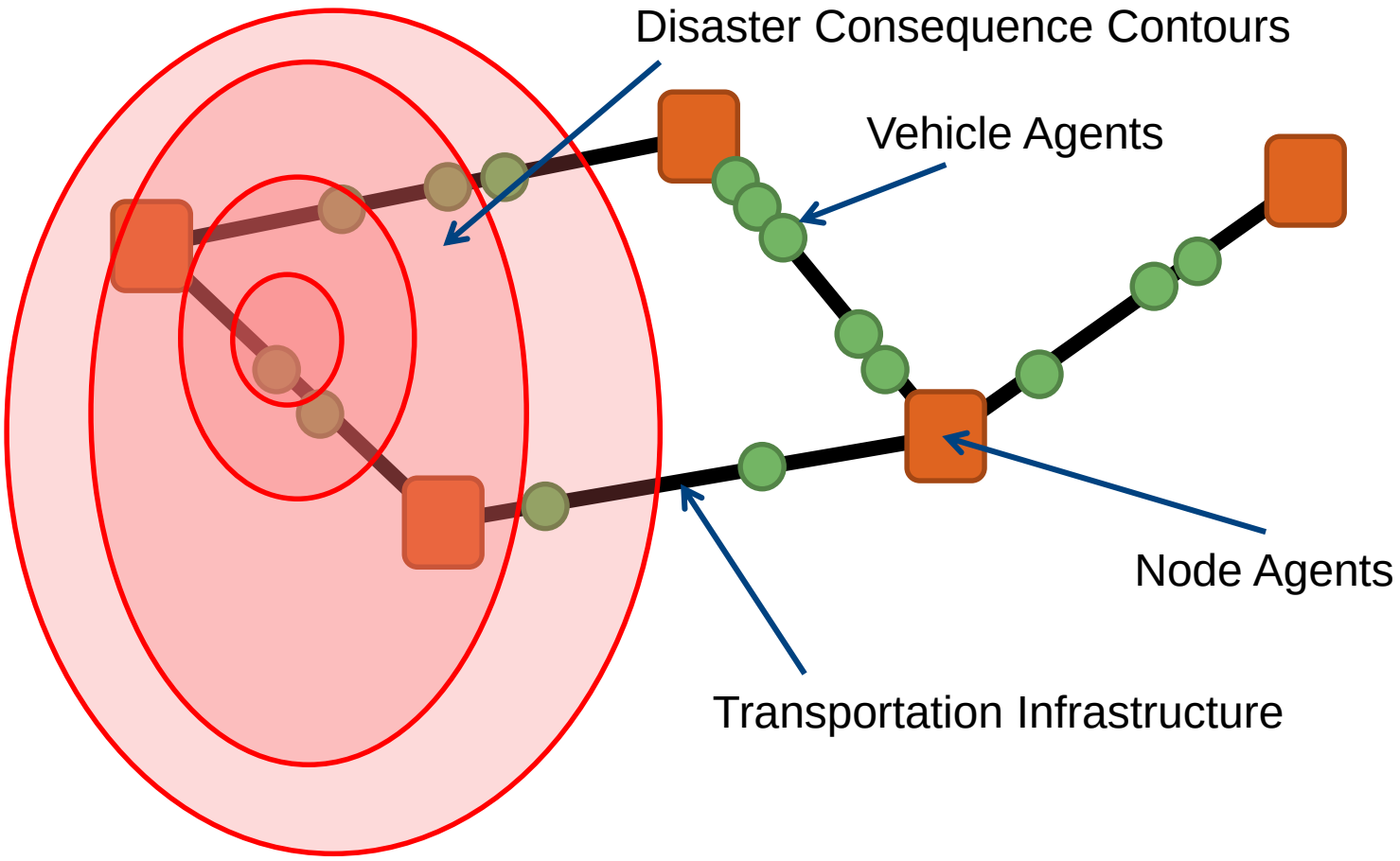
- Disaster modeling represents a unique challenge:
  - Natural vs. man-made
  - Unique environments and physical consequences
  - Numerous scenario possibilities and threat vectors
  - Disaster response strategies rarely implemented as planned
  - Unknown human reactions
- Goal: Produce downstream model outputs to test policy decisions and input to other models



Using Simulation for Disaster Modeling

- Simulation is good way to evaluate the space of potential scenarios for a variety of reasons
  - Disaster event that has never happened (and we hope never does)
  - Human response is a fundamentally unpredictable phenomenon which deterministic models have limitations in incorporating
  - Often do not need exact answers, but instead need to compare alternatives (ordinal analysis)
- To truly capture the most important dynamics of a disaster event, the model should sometimes exhibit unexpected outcomes
  - Emergence is key principle in modeling human systems
  - More simulation runs = better, build distribution of outcomes
- Key challenge: How do I validate a disaster model?
- Case study: IND Evacuation Model

Framework

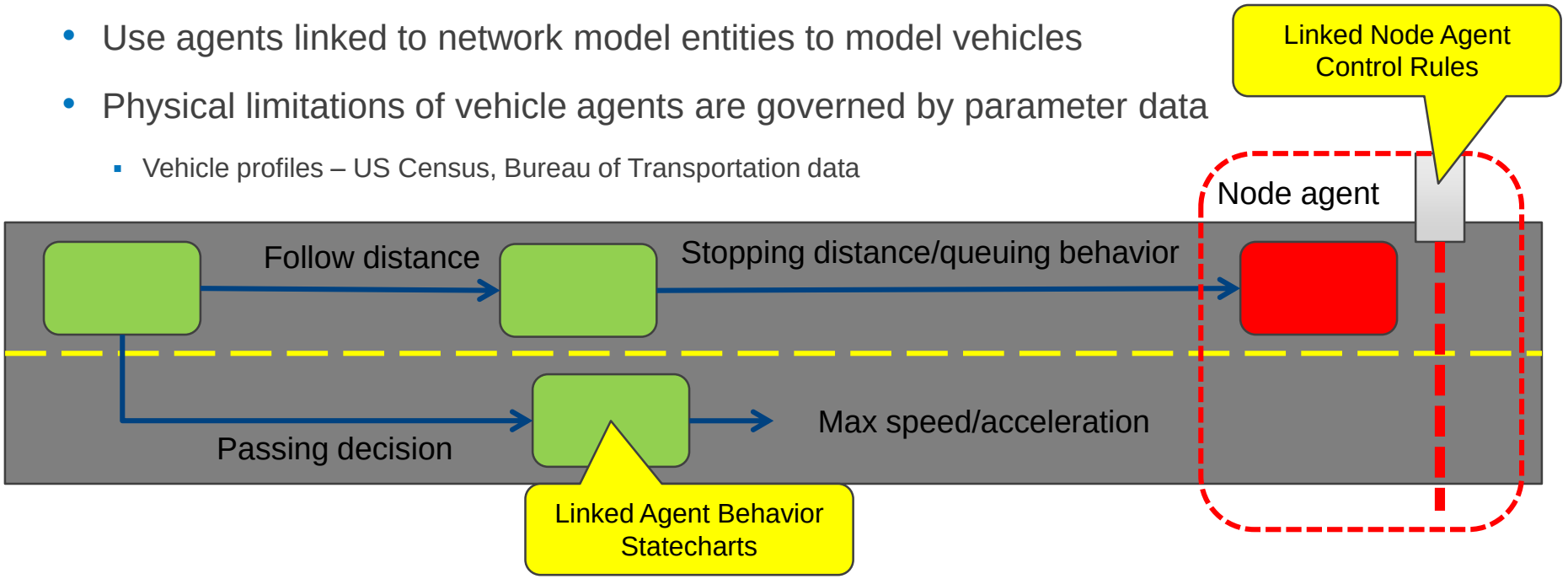


Environment

- Road networks are commonly modeled using node-network layout
  - Data on road layouts from GIS databases
  - Local highway agencies keep data on speed limits, lane capacity
  - Generate layout of node locations and network connections from configuration files
- Use agents as node points to allow greater control
- Must incorporate changes to network through dynamic events as disaster event unfolds, for example:
  - Flooding of roads
  - Destruction of bridges and buildings
- Incorporation of major evacuation routes is often enough to capture major emergent evacuation patterns based on sensitivity studies

Agents – Physical Properties

- Use agents linked to network model entities to model vehicles
- Physical limitations of vehicle agents are governed by parameter data
  - Vehicle profiles – US Census, Bureau of Transportation data



- Note: this library of models was built before the AnyLogic road library was available
  - Future updates could incorporate hybridization of existing model with these models – tradeoffs in model scale and runtime

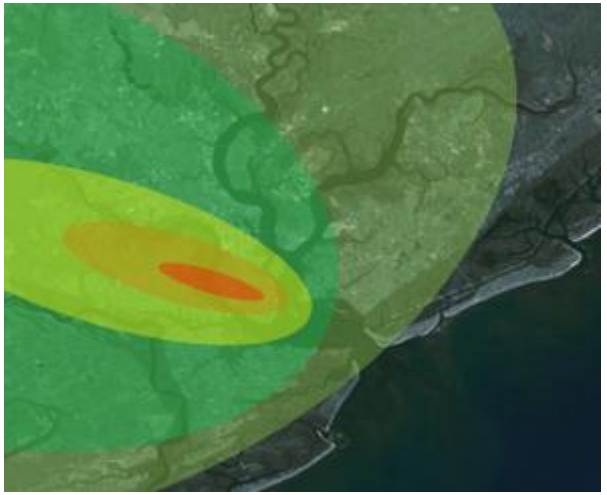
Agents- Behavior

- Drivers are irrational under normal circumstances, so how will behavior change during a mass evacuation?
  - Data from disaster response studies, past mass evacuation events informs rational/irrational driving behavior
- Dynamic route finding – studies show that on a familiar road networks, drivers will make tradeoffs between evacuation route attributes
  - Closest “exit”
  - Time spent waiting/stopped
  - Perceived asymmetric information
  - Route tables calculated on model initialization, allows for more efficient dynamic optimization of route decisions
- In the case of the IND model, there are several interlinked agent state sets that are dynamically tracked and updated
  - Priority set – Evacuate/shelter/seek medical attention/find persons of interest
  - Physical/health state - Flash blindness, blast damage, accident injuries, fatigue, sickness
  - Radiation dosage received – linked to health state and priority set
- All of these behavior states linked to physical vehicle movement parameters
  - Vehicles can experience stoppages as drivers become incapacitated

Disaster Events

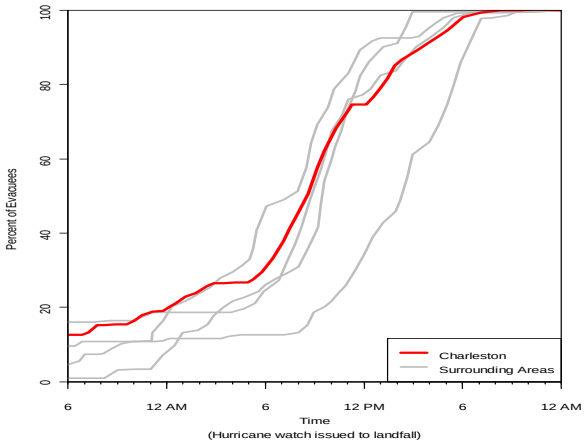
- Use dynamic contours to track regions of disaster consequences
  - These are often derived from other simulation models to compartmentalize processing requirements
  - Contours update in real time based on predicted weather patterns, land cover, any other relevant factors
- Multiple interlinked contour sets can be adapted to represent almost any disaster scenario
  - Flooding levels
  - Fire spread
  - Damage path
  - Contamination/fallout spread
- IND model uses 2 main contour sets
  - Blast radius levels – fireball and overpressure force contours
  - Fallout distribution – radiation levels in air and deposition on ground from various radioactive particle types

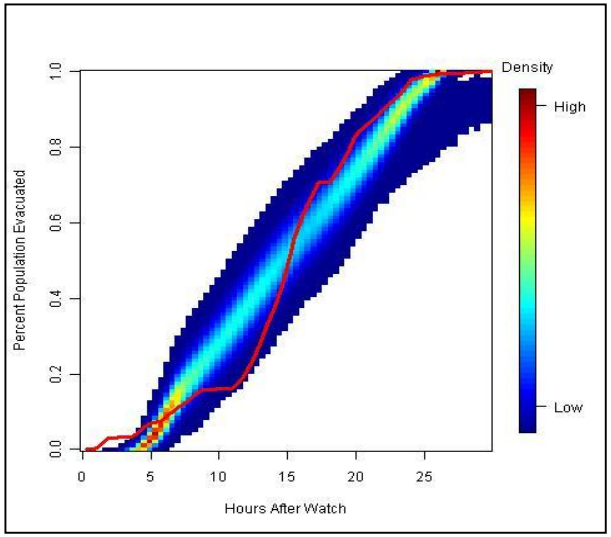
Examples of Disaster Contours



Calibration/Validation

- Critical step in proving validity of simulation model
  - Use evacuation data from past disasters to set accuracy targets
  - Calibrate agent behavior variables from initial values
- What if there is no historical data available?
  - Use validation data from other major transportation flow events
  - Example: for IND model, match to hurricane evacuation
    - Use same transportation network to proxy for familiarity
    - Sensitivity analysis based on other disaster events and survey data to establish parameter bounds
  - Match traffic conditions to time of day – initialize agents at time of event based on traffic camera data
- Iterative calibration process using repeated runs
  - Used custom optimization algorithm for this application – repeated batches of Monte Carlo runs used with custom Java scripting
  - Optimized simulation parameters are often distributions with associated uncertainty parameters





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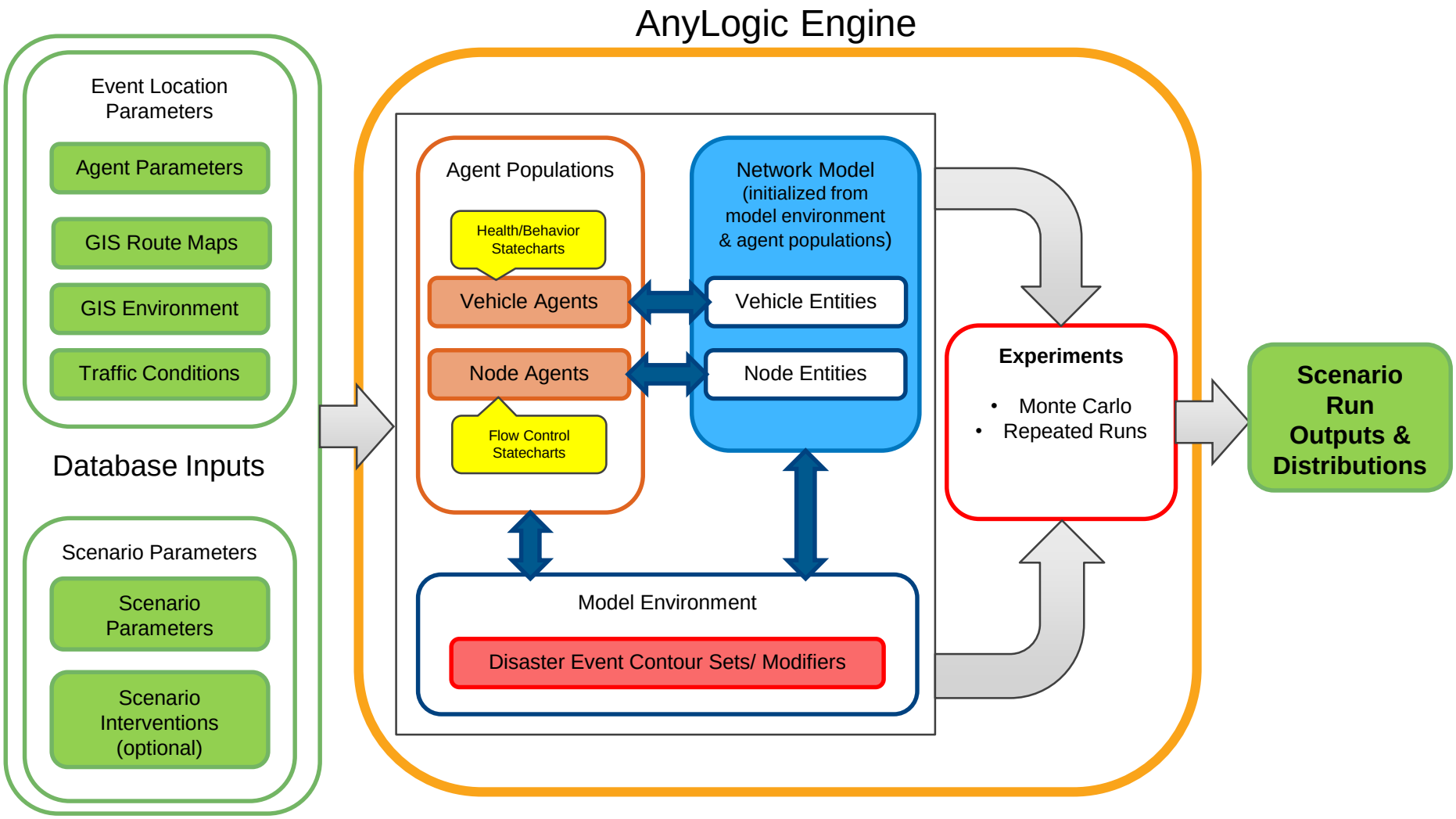
Calibrated Model



Results

- For IND scenario, wanted to test the effectiveness of a 48 hour shelter-in-place order
  - Intended goal – reduce radiation dosages received during uncoordinated mass evacuation
  - Compare 2 sets of runs – immediate evacuation vs. shelter in place order
    - Some households assumed to ignore evacuation order or shelter order
    - Some agents proceed to designated shelter areas
- For large INDs, simulation shows that shelter in place order significantly reduces dosage received as well as cases of severe radiation poisoning

Policy Planning

- Use simulation to test of different disaster response strategies – find best response strategy among several likely options
- Can incorporate emergency responder agents
- Can incorporate different scenario interventions
  - Test different traffic flow control configurations using node agent behavior
- Interchangeable model components
  - Different locations for same disaster scenario
  - Different disaster for same location

Questions?