Complex Adaptive System of Systems (CASoS) Engineering Initiative
http://www.sandia.gov/CasosEngineering/

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Mitigating Infectious Disease Outbreaks in Medical Facilities with Incomplete Vaccination

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Complex Adaptive Systems exist at a variety of scales

- Cellular signaling
- Biological organisms
- Ecologies
- Cities and Megacities
- Interdependent infrastructure
- Government, political, educational, healthcare, financial, economic systems and their supply networks
- Global energy system and climate change
- Our work focuses on large systems: regional, national, global
- We leverage the scaling properties for inspiration on ways to handle large systems

Infectious Disease Modeling

- Collaboration between VHA and Sandia CASoS Engineering Initiative to model pandemic influenza 2005-present
- Use of community level social network models to evaluate impact of various policy cocktails for control of disease spread
- In the absence of widely available effective vaccination, social distancing efforts need to concentrate on identifiable backbone of infection spread, especially schools
- Similar techniques used to model spread of nosocomial infections and intervention strategies

Varicella

- Worldwide estimates of Varicella zoster virus
  - 80% of children under 10 have had varicella
  - 95% of adults are immune
- Virus highly communicable through breathing or touch
  - Illness follows 10-21 days after exposure
  - Contagiousness occurs 1-2 days before rash appears, lasts until rash crusts over
- Complications include pneumonia, brain inflammation, sepsis, bone infections
- Immuno-compromised individuals, pregnant women and newborns at higher risk

San Juan, Winter 2011

- Patient with varicella in VA Community Living Center
- Immunity rates lower than in Continental US
- Infection spread patient-patient, patient-staff
  - 13 cases within a short time – 2 patients, 11 staff
  - Difficulty getting enough vaccine quickly
  - Concern over extended waves of infection
  - Concern for hospital operations caused by vacancies, administrative leave for infected and exposed individuals
- Fast-turn investigation leveraging previous modeling experience
- Rapid response by VA prevented outbreak

Hospital Vaccination Policies

- Variability in policies
  - Complicates universal expectations and policy formulation
  - Non-mandatory vaccination policies result in low vaccination rates for health care workers
  - Networks of hospitals can contribute strongly to HAI incidence
- Heterogeneity in immune status among personnel
  - Medical, technical, administrative, maintenance staff
  - Patients
  - Visitors (teratogenic during pregnancy)

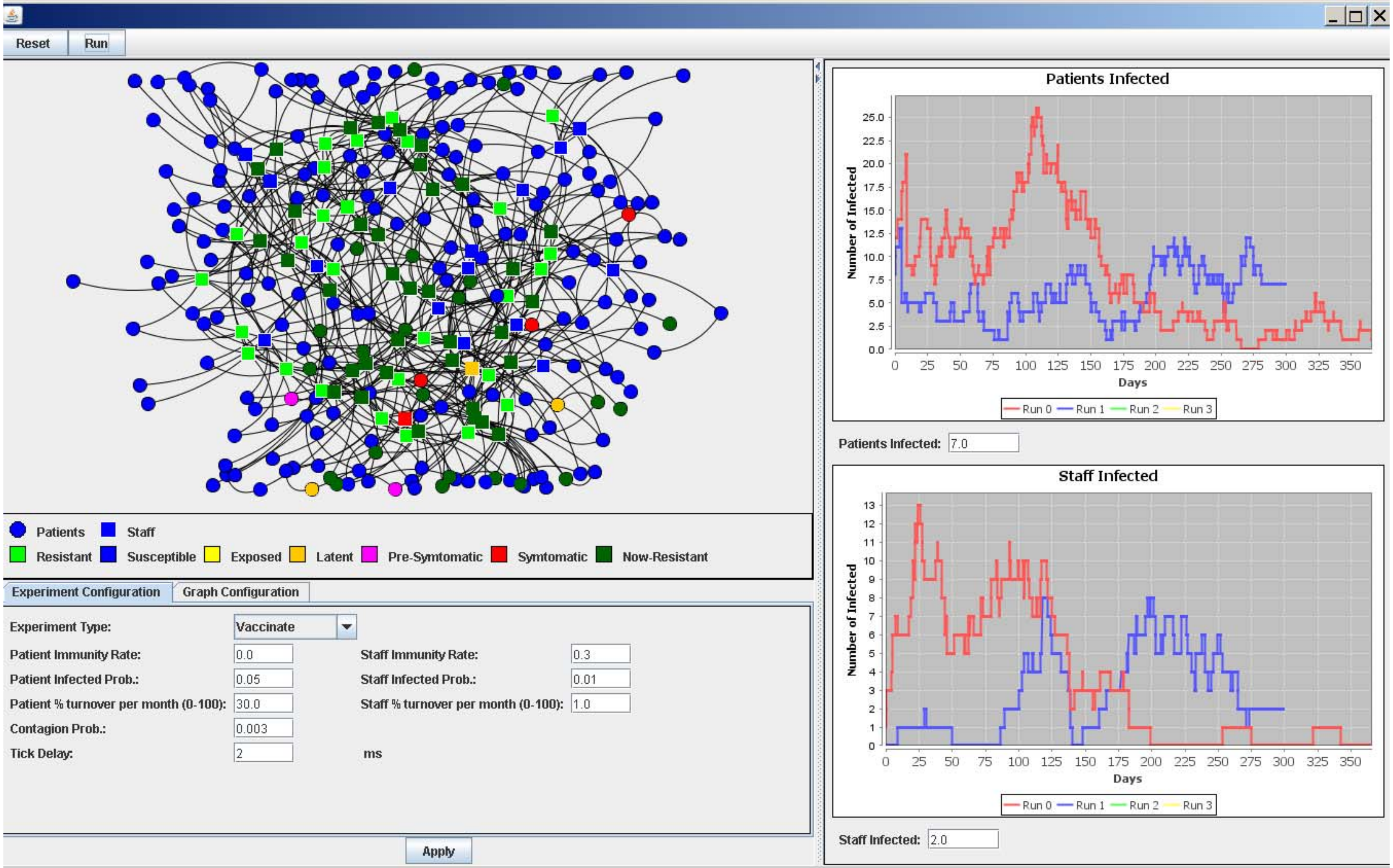
Two Level Modeling Approach

- Which facility-level interventions will be most effective in containing an outbreak of infectious disease?
- What system-level interventions will best mitigate the negative impacts of those interventions
- **Example:** Furloughing susceptible staff members creates staffing shortages, affecting hospital operations

Clinical Model of Varicella Dynamics

- Social network model with degree distribution dependent on roles of actors
- Investigate the effects of differential topologies, immunity percentages
- Model the contributions of mixes of intervention strategies
    - Prophylactic vaccination
    - Preemptive vaccination
    - Social Distancing

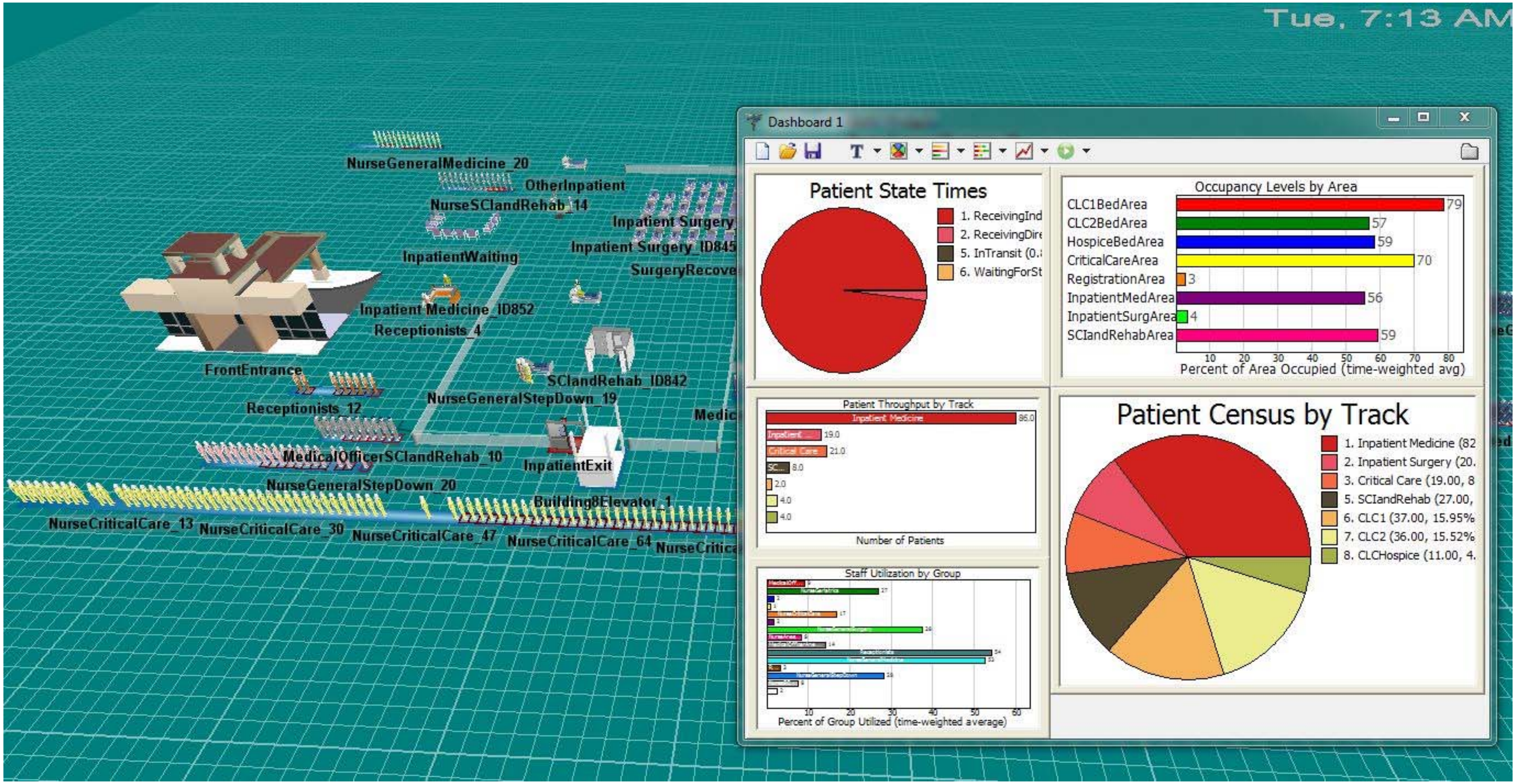
Contagion Model GUI



Facility Operations Model

- Goal: model the impact of interventions on hospital operations
  - Personal Protective Equipment (PPE)
  - Isolation
  - Furloughing staff
- Evaluate higher order impacts of infection-oriented interventions
- Initial version: discrete-event simulation using FlexSim Healthcare
  - Hospital is a large network with interdependent wards
  - Discrete event simulation allows for representation of non-stationary distributions that are difficult to evaluate in closed form

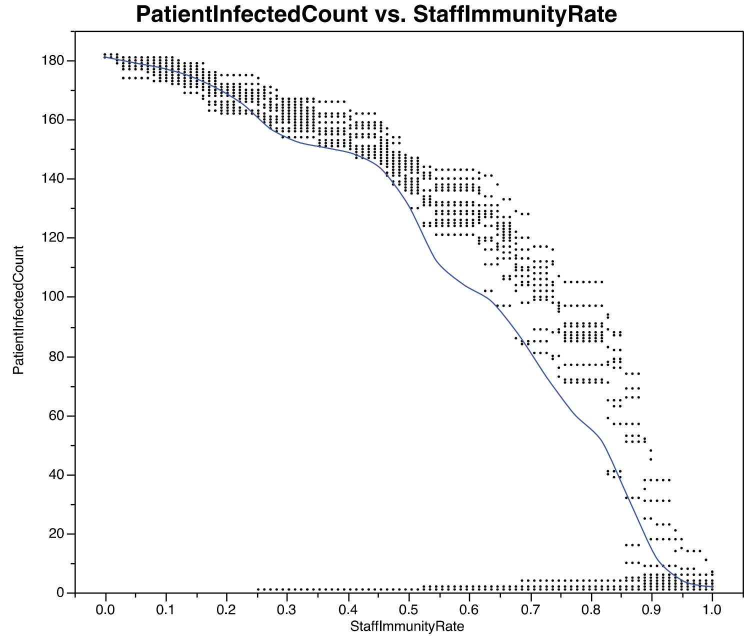
Facility Operations GUI



FlexSim Healthcare 3.1.4

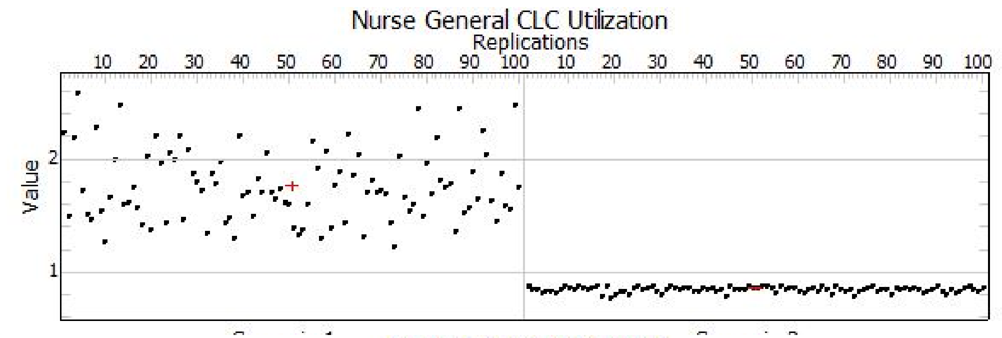
Results – Infection Model

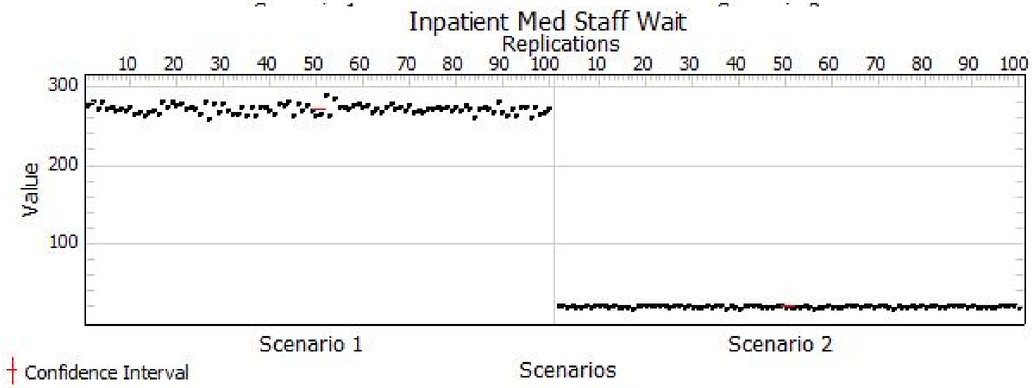
- Staff Immunity is the key to controlling infection
- Immunity above 0.95 minimizes risks
- After event begins, furloughing susceptible staff can increase immunity rate
- Prior knowledge (from serological exams and immunization) is necessary to intervene efficiently

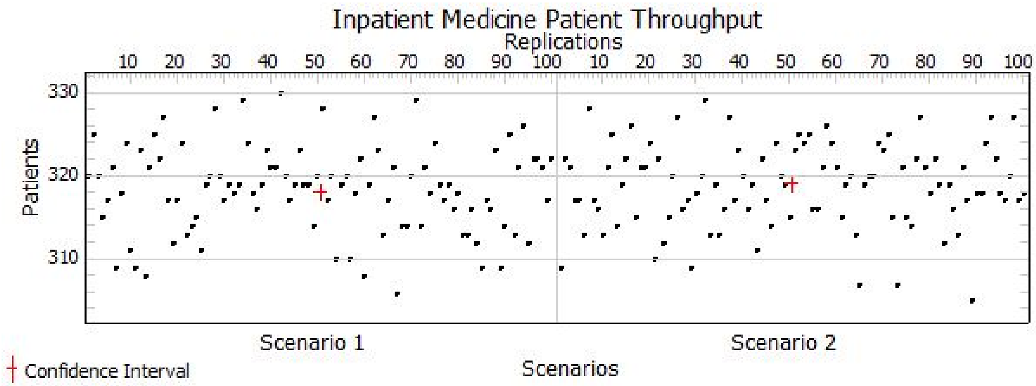


Output – Hospital Operations

- Simulation allows for examination of impacts of interventions (e.g. furlough) focused on different personnel types and hospital units
- Currently represent six active patient tracks and 15 staff types
- Pursuing additional data to increase resolution of the model and validate patient flows







Conclusions

- Interventions done prior to incident are most effective
  - VZV serologic screening at time of employment
  - Immunization requirements
- Interventions can reduce operational effectiveness of facility
  - Reduced ability to identify susceptible personnel with confidence can increase number furloughed
- Transferring in known immune personnel can mitigate operational impacts
  - In extreme cases, some patients may need to be transferred to other facilities