Hybrid Agent-Based/Discrete Event Simulation Models for Analysis of Health Care Delivery Systems

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Introduction

• VA St. Louis Healthcare System
• VA ORD HSR&D Merit Review Pilot Study
  – PPO 11-167, “Simulation Modeling for Implementation Analysis” (PI-Day)
• Equipment/Software provided by 2009 VHA Innovations Award #123 (PI-Day)
• No Conflict of Interest to Report
• Data and Some Figures Previously Published[1] or in Review.
• Study Reviewed and Approved by VA St. Louis Healthcare System IRB.

Introduction

• How can simulation inform policy and practice?
• How can simulation be used to improve health services delivery?
• How can simulation improve population health?
• Specifically, can we use simulation to analyze the consequences of increasing the duration of the screening interval for DR?
Poll Question

• Who has computer simulation modeling experience?
  – I am a model developer.
  – I directly use models developed for my institution.
  – I don’t use them, but my institution does.
  – I have heard of it, but my institution does no simulation modeling.
  – I have never heard of simulation modeling.
  – Isn’t simulation something about those creepy mannequins?
Complex Systems in Healthcare

- Multiple Dependencies
- Complex Interactions
- Dynamic Behavior
- “Butterfly Effect”
- Feedback Loops
- Adaptive
- Memory Dependant
- Nonlinear State Variables
- Indistinct Boundaries
Complex Systems in Healthcare
Model Classifications

• Hybrid
  – Combination of multiple methods
  – Combination of multiple time measurements
• Agent-based
  – Individuals within a population
• Discrete Event
  – Step-by-step model progression
• Multi-scale
  – Model unfolds on two time-scales
Discrete Event Simulation

- Computer simulation of real-time processes
- Decomposes systems into basic elements
  - Entities (patients, patient records, lab samples)
  - Resources (Physicians, nurses, equipment)
  - Locations (Exam rooms, queues)
  - Paths (Networks linking locations)
- Process Flow
  - How do entities consume resources and proceed along paths between locations?
Discrete Event Simulation

• Rudimentary Simulated Eye Clinic
• Performs two functions
  – Eye screens
  – Laser eye surgeries (PRP)
• Represents the environment of interaction for the agents
  – Agents compete for clinical time, resources
Agent-Based Models

- Agents are objects with individual rule sets and attributes
- Capable of autonomous decision making
- Agents can interact with each other, and their environment
- Ideal for modeling populations of individuals
  - Birds in a flock, fish in a school
  - Cells in a tumor
  - Cars in traffic
Agent-Based Models

• Each agent represents a single Veteran
• Imbued with individual characteristics
  – BMI, recent A1c, BP, age, duration of DM, presence of DN, stage of DR, etc.
  – Updated annually
• Rule set governing how DR advances
• Algorithm for when to visit clinic
  – Determine visitation schedule and then queue for availability
Agent-Based Models

- Our Agent-Based Veteran includes:
  - A statechart governing progression of diabetic retinopathy
  - Numerical fields capturing the Veteran’s health status and demography
  - A function attached to a life-table to predict expiry
  - An “event” which updates the Veteran annually
  - An “entity generator” which communicates with the DES clinic
  - Multiple regression model of DR progression
Agent Based Veteran
Integrating the Models

• The Agent periodically enters “clinicVisitState”
  – Generates an “Entity”
  – Passes all relevant information from Agent to Entity
  – Sends Entity to the DES Clinic

• The Entity negotiates the clinic
  – All entity activity governed by external flowchart
  – Receives indicated care according to individual needs
  – Passes updated information back to Agent
Integrating the Models

**Agent-Based Veteran**
- **Covariates:**
  - Age, Gender, Duration of DM, BMI, HbA1c, Nephropathy, Hypertension, Dyslipidemia, Tobacco Use

**Annual Update**
- Calculate DR state
- Increment:
  - Age, Duration of DM
- Calculate probability of expiry

**Eye Clinic Visit**
- Undergo eye screen
- If new PDR and no previous PRP then:
  - Schedule PRP laser surgery.
- Update health status
Integrating the Models

**Discrete Event Simulation**
- Replicates St. Louis VAMC eye clinic
  - Diabetic eye screens
  - PRP laser surgery suite
- Agent-based Veteran (ABV) creates an entity, passing all health information from agent.
- Entities enter eye clinic, queue for annual/biannual screens
- If Entity exhibits new PDR, entity is scheduled for PRP laser surgery
- Updates to entity health status are passed back to the ABV, and incorporated into population model

**Agent-Based Population**
- Replicates population of diabetic Veterans seeking treatment for diabetic retinopathy (DR) at the St. Louis VAMC eye clinic
- Each ABV is initialized with unique parameters of age, gender, duration of DM, etc. (table X), distributed according to abstracted data
- Statechart based algorithm tracks progression of DR over length of simulation
- Algorithm incorporates effect of interaction with DES clinic into DR progression

**Seeks Screening and Treatment** (Creates an entity)

**Updates Health Status** (Passes updates to agent)
Experiment

• Conduct 10 simulation runs of 10 years each for each of five groups

• For each group, screen veterans with no DR, or with Background DR, with from one to five years between screenings

• Examine the incidence of vision loss in the population at the end of 10 years

• Simulation allows us to isolate the contribution of screening interval to progression.
Results

• Primary outcome measure: number of Veterans reaching state “Vision Loss”
  – No significant difference between annual and biannual groups
  – Significant increase (P<.01) between 1 year interval and 3 year interval (from 60 to 65 Veterans)
  – Increases as screening interval extends to 4, 5 years present, but not significant (from 65 to 67 Veterans)
  – Reduction of 76.5 appointments per year between annual and biannual screening groups
Discussion

- Generally desirable to adopt policies which provide equivalent or improved care at lower cost
  - Provide additional care at same cost
- Simulation allows us to identify candidates for such policies
  - We can test many changes and implement the most promising
- Can help reduce waste in health delivery by identifying unnecessary outlays
  - Increased access through reduction of redundant screens
Discussion

• Simulation structure permits bidirectional analysis
  – Changes to clinical policy measured in population-level outcomes
    • Management of chronic disease
  – Changes to population demographics/predictors measured at level of demand-for-services, queue lengths.
    • Management of healthcare facilities
  – Integrates populations and institutions in a comprehensive model
Discussion

• Simulation allows us to conduct risky, ambitious, or unethical experiments
  – Including BDR in experimental group goes beyond what we see in real-world trials
  – There is no risk of harm to real patients if there are disastrous consequences
  – Must take great care in translating risky results to real world trials
  – Can function as hypothesis generation for health services research
Discussion

• Results complement other real-world and simulated studies
Limitations

• Cross-sectional patient data
  – Follow up work will require improved epidemiology

• Does not predict disease progression in any individual
  – Only aggregate information should be considered informative

• Simulations do not replace medical judgment
  – Provide useful supplemental evidence to incorporate into human studies
Conclusions

• Simulation can inform policy and practice
  – Using sophisticated methods to model proposed policy interventions and test them in silico
  – Supplying evidence that practice changes are safe and effective for the long-term

• Simulation can improve health services delivery
  – Determine optimal screening schedule, allowing additional appts to be made for alternative care
Conclusions

• Simulation can improve population health
  – Identifying broad risk-categories for appropriate screening intervals
  – Optimizing delivery of care to individuals most in need of services
  – Target interventions likeliest to have large effect-sizes
  – Providing data-driven analysis to encourage adoption
Conclusions

• Simulation may be able to inform practice regarding the screening interval for DR
  – Results concur with the accepted evidence
  – Inclusion of BDR in experimental group means that care must be taken in adopting results
  – Would require careful retrospective study of administrative data to support/confirm results
  – Any prospective trials must be carefully planned and conducted by physicians, etc.
Poll Question

• Who is interested in deploying simulation modeling?
  – This has definite potential for my institution.
  – I would be interested in exploring options in the future.
  – While interesting, I’m not sure simulation meets my institution’s needs.
  – I definitely am not interested in simulation modeling.
  – We already have a bunch of creepy mannequins.
Further Reading

Acknowledgments

• I wish to thank:
  – My co-authors Nathan Ravi, MD, PhD; Hong Xian, PhD; Ann Brugh, PsyD
  – Co-workers Jeffery Scherrer, PhD; Angelique Zeringue, MS, PhD(c); Lauren Garfield, PhD
  – VA ORD HSR&D
  – VHA Innovations
Questions & Comments