Methicillin resistant *Staphylococcus aureus* transmission reduction using Agent-Based Discrete Event Simulation

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Agenda

Motivation

Methodology

Implementation

Validation and Testing

Project Schedule

Questions

Motivation

- The spread of infection is a huge problem, particularly in large, tertiary-care hospitals across the world
- One of the most prevalent types of infection is **methicillin resistant *Staphylococcus aureus*** (MRSA), the cause of close to 300,000 hospital-acquired infections and 20,000 deaths per year
- The goal of this project is to model the transmission dynamics of MRSA within the University of Maryland Medical Center, primarily through simulating the direct interactions between health care workers and patients

Literature Review

1. Cooper, Medley, and Scott (1999) examined the effects of transmissibility, colonization, patient length of stay, hand washing, and detection
2. Raboud *et al* (2003) determined the impact of patient screening, patient cohorting, hand washing, and patient risk levels
3. McBryde, Pettitt, and McElwain (2007) investigated the transmission dynamics of MRSA in an ICU
4. Beggs, Shepherd, and Kerr (2008) demonstrated the diminishing returns of increased hand hygiene compliance

Methodology

- Literature has simulated transmission dynamics by developing rates of change for patients and health care workers becoming colonized with MRSA, and integrating these expressions over the simulation period
- Shift focus towards modeling the **interactions** between patients, health care workers, and visitors
- Can achieve this goal through the use of **agent-based modeling** and stochastic **discrete event simulation**

Agent-based Modeling (ABM)

- Seek to generate macroscopic (emergent) behavior from modeling microscopic interactions
- ABM requires:
  - Definition of agents and their behaviors
  - Scope of interactions between agents
  - Optional: Spatial representation of environment

Meet the Agents I

- Patients
  - Admitted and discharged to different units within the hospital
  - 3 states: Susceptible, colonized, and infected
  - 2 levels of risk: Low or high
  - ICU patients or previously colonized patients are deemed high risk
  - Can be decolonized using treatment
- Visitors
  - Each visits a particular patient in the hospital
  - Could possibly be carriers of MRSA, to be transmitted to patients only

Meet the Agents II

- Health Care Workers (HCWs)
  - Nurses
    - Provide primary care for small numbers of patients
    - 2 states: Susceptible and colonized
  - Physicians
    - Provide care for large numbers of patients, although with minimum incidence of hand contact
    - 2 states: Susceptible and colonized

Discrete Event Simulation (DES)

- Three 'schools of thought'
  - Time stepped DES: Propagate simulation time until an event time is reached
  - Event oriented DES: Jump to discrete points in time where event occurs
  - Process oriented DES: Model each simulation entity as a process, with each transitioning between active and passive states
- Stochastic vs. Deterministic: A stochastic implementation will be used, requiring the use of Monte Carlo methods

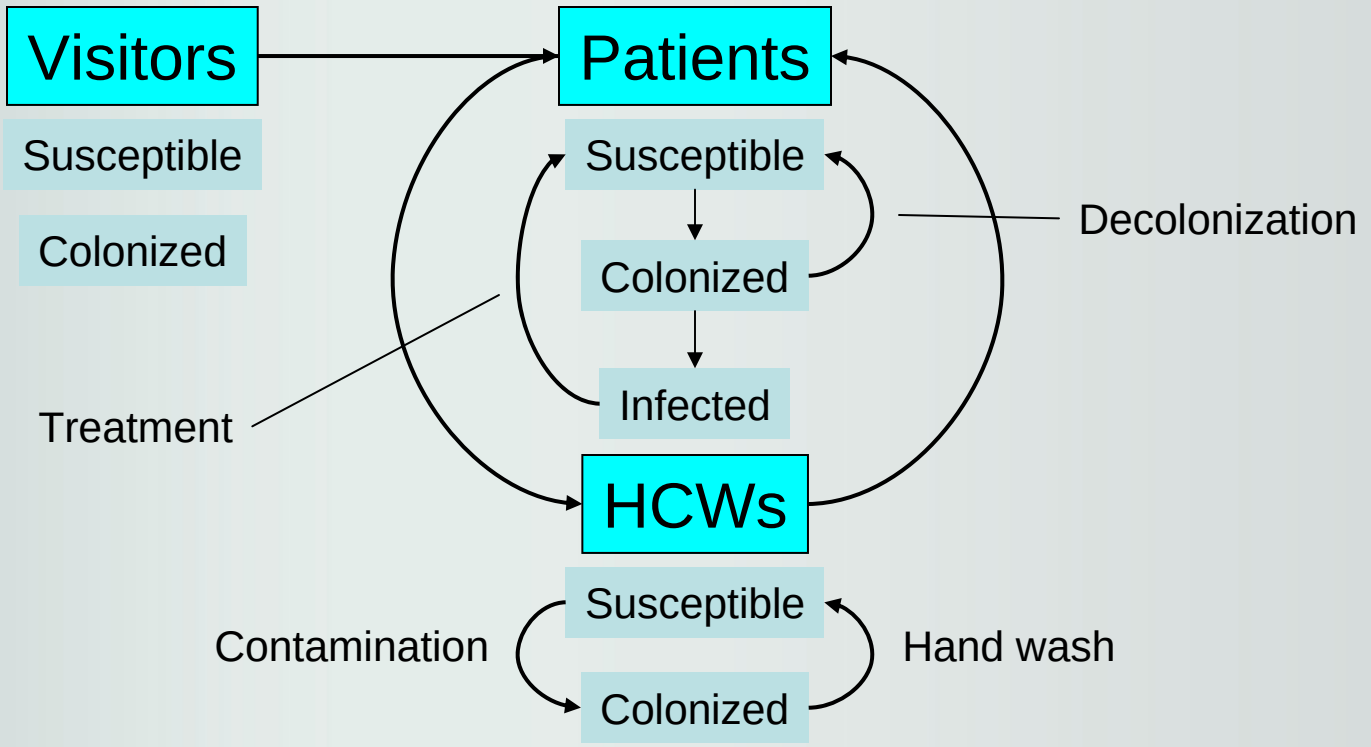
Process Oriented DES

- Patients are modeled as a **process**, from the point of admission through discharge
- HCWs and visitors are modeled as **resources** to be requested by the patient during their stay
- Software will simulate the interactions between patients, HCWs, and visitors through the use of a **scheduler**, which processes the requests by patients and services by HCWs and visitors

Transmission Dynamics

- Colonized HCWs and visitors can transmit MRSA to patients through direct hand contact, with probability $p(r)$, which is a function of the risk level of the patient
- Colonized or infected patients can transmit MRSA to HCWs with probability $p(s)$, which is a function of the state of the patient
- HCWs can become decolonized by washing their hands
- Patients can become decolonized through treatment, once identified as colonized or infected

Interactions and State Transitions



No environmental effects

Infection Control Programs

- Hand hygiene compliance
- Patient screening
- Patient isolation
- Patient cohorting
- Decolonization

Infection Metrics

- **Successful introduction rate**: No. of secondary cases
- **Ward prevalence**: Percentage of days on which at least one colonized patient was present
- **Colonized patient days**: Percentage of total days spent as a colonized or infected patient
- **Basic reproduction number, R_0**: Mean number of secondary cases as the result of a single primary case

Implementation

- Python: A dynamic object-oriented programming language with useful modules
  - NumPy: Multi-dimensional array processing package
  - SimPy: Process oriented DES architecture package
  - SciPy: Scientific computation package
- Object-oriented programming (OOP)
  - Design object classes and methods to represent agents and their behavior
  - Encourages code recycling through inheritance and encapsulation
- Also considered: C/C++ and MATLAB

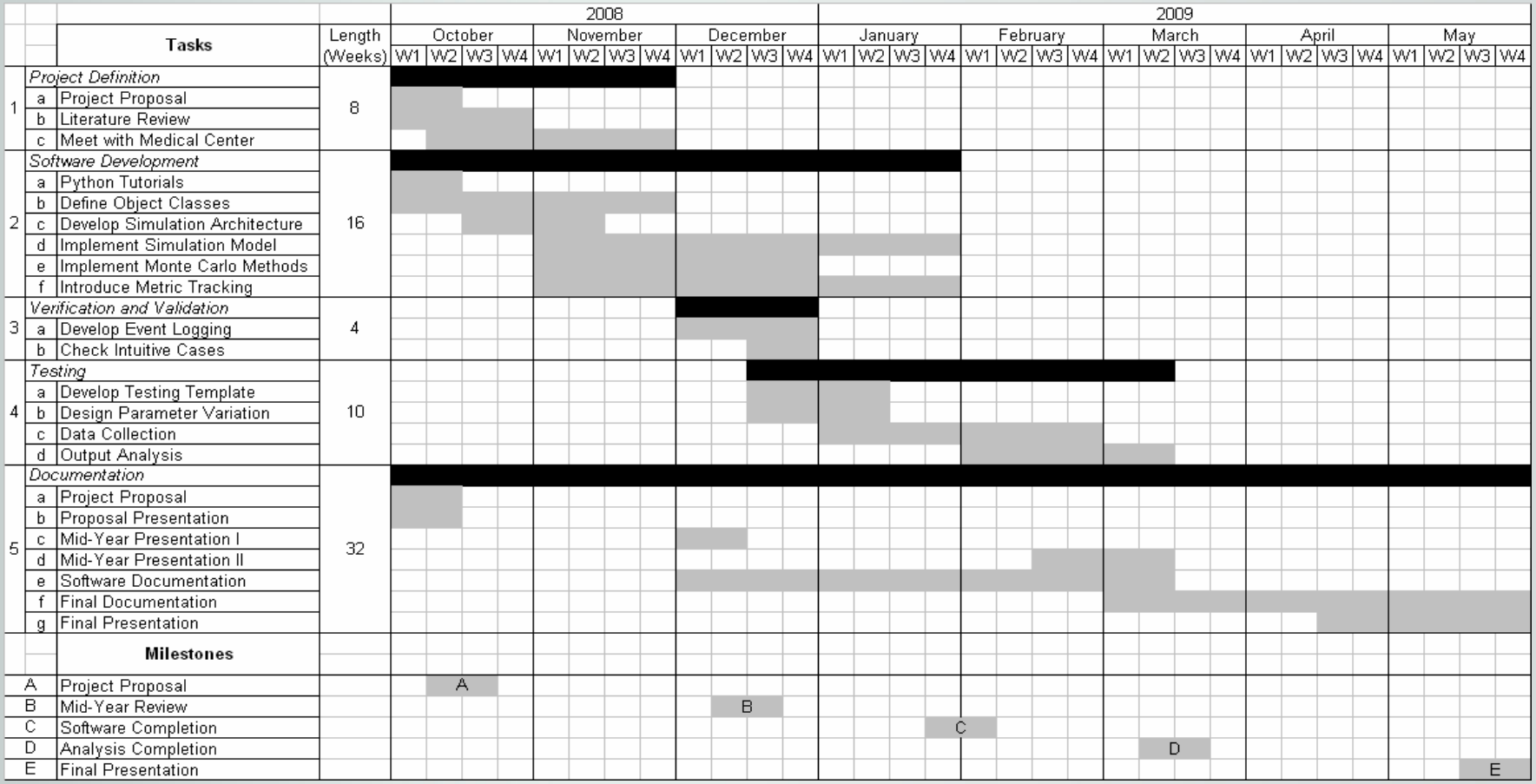
Software Development

- Design agent classes and methods
- Develop simulation architecture
- Incorporate Monte Carlo methods
- Define simulation parameters
- Implement infection model
- Introduce metric tracking

Validation and Testing

- Trend matching
  - Increasing hand hygiene compliance decreases the onset of MRSA, but with diminishing returns
  - Decreasing hand hygiene compliance past a threshold value causes massive increases in MRSA transmission
  - Only screening all or almost all of admitted patients shows a noticeable decrease in transmission
  - Increasing the HCW/patient ratio to unity effectively eliminates transmission
  - Isolating colonized and infected patients reduces transmission

Project Schedule



		Tasks	Length (Weeks)	2008												2009															
				October				November				December				January				February				March				April				May			
				W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4
1		*Project Definition*	8																												
	a	Project Proposal																													
	b	Literature Review																													
	c	Meet with Medical Center																													
2		*Software Development*	16																												
	a	Python Tutorials																													
	b	Define Object Classes																													
	c	Develop Simulation Architecture																													
	d	Implement Simulation Model																													
	e	Implement Monte Carlo Methods																													
	f	Introduce Metric Tracking																													
3		*Verification and Validation*	4																												
	a	Develop Event Logging																													
	b	Check Intuitive Cases																													
4		*Testing*	10																												
	a	Develop Testing Template																													
	b	Design Parameter Variation																													
	c	Data Collection																													
	d	Output Analysis																													
5		*Documentation*	32																												
	a	Project Proposal																													
	b	Proposal Presentation																													
	c	Mid-Year Presentation I																													
	d	Mid-Year Presentation II																													
	e	Software Documentation																													
	f	Final Documentation																													
	g	Final Presentation																													
		Milestones																													
A		Project Proposal			A																										
B		Mid-Year Review											B																		
C		Software Completion																C													
D		Analysis Completion																						D							
E		Final Presentation																													E

Questions?

Acknowledgements

Dr. Harold Standiford, UMMC

Carter Price, University of Maryland

Dr. Edward Wasil, American University

Catherine Dibble, Aiki Labs