Harnessing multiple models for outbreak management

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Multiple models for epidemiological systems

- Endemic and epidemic diseases of significant public health concern trigger multiple modeling efforts (e.g. influenza, Ebola, Zika, COVID-19)

- Considerable uncertainty impedes projections and decision-making
## Comparison of model recommendations from a consortium

<table>
<thead>
<tr>
<th>Model</th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
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<tbody>
<tr>
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<td>Bad</td>
</tr>
<tr>
<td>Model 2</td>
<td>Good</td>
<td>OK</td>
<td>Bad</td>
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<tr>
<td>Model 3</td>
<td>OK</td>
<td>Good</td>
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</table>

How do policy makers choose which model recommendations to use when developing policy?
Harnessing the power of multiple models

- Synthetic approaches use ensemble averaging/superensemble modeling
e.g. Krishnamurti et al (1999) for weather and climate projections
e.g. Anderson et al (2017) for fisheries
Applied Focus: Approaches

• Structured Decision Making
  – Formal tools for analyzing decisions

• Expected Value of Information
  – Understanding the importance of uncertainty to a decision maker

• Adaptive Management
  – Making repeated decisions in the face of uncertainty

Shea et al 2014 PLOS Biology
Harnessing multiple models for outbreak management

Expert elicitation methods and a structured decision-making framework will help account for risk and uncertainty

By Katriona Shea, Michael C. Runge, David Pannell, William J. M. Probert, Shou-Li Li, Michael Tildesley, Matthew Ferrari

Shea et al May 8 2020 Science

First exercise on reopening strategies running now:
https://midasnetwork.us/mmods/
Overview

Merging ideas from three fields:

- Decision theory (in the face of uncertainty)
- Multiple model projections for different objectives and interventions
- Expert judgment and elicitation
Making the most of multiple models

**Problem**
In structured decision making (SDM), the decision maker (DM) first defines the problem.

**Objectives**
DM defines the management objectives, identifying specific outputs they wish to see modeled (the metrics used to quantify each management objective).

**Interventions**
DM defines the management interventions, identifying specific inputs that they wish to see modeled (the multiple scenario settings that represent different policy options).

**Projections**
Coordinates interactions between modeling groups to minimize sources of bias.
- Independent model projections
- Feedback and structured group discussion
- Updated independent projections
- Synthesis of multiple updated projections

**Decision analysis**
Decision analysis is used to analyze the model outputs and their implications for the relative merits of different interventions.

**Implementation**
The selected strategy is implemented by the DM.
First elicitation exercise: post lockdown strategies

5 objectives - minimize:

- cases, deaths, peak hospitalizations,
- probability of a new outbreak, number of days workplaces closed

4 interventions:

- full closure, reopen workplaces 2 weeks after peak,
- reopen workplaces when cases at 1% of peak, immediately open all workplaces

Ongoing process: see https://midasnetwork.us/mmods/
Analyses

• Aggregation methods used in expert elicitation exercises
• Value of information approaches
• Ranking of actions – examples from FMD and Ebola
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<th>Duration</th>
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<td>A</td>
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<td>131</td>
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Probert et al.,
*Epidemics* 2016

Foot and Mouth Disease

Dr. William Probert
Ebola: case minimization
‘How big?’ vs ‘How to make it smaller?’

Reducing funeral transmission
Reducing community transmission
Reducing case fatality ratio
Reducing hospital transmission
Increasing hospitalization rate
Future elicitations

- Different governance levels
- Vaccine trial locations
- Test allocations during reopening

- And hopefully many more. These methods can be applied to any decision-making process involving multiple models
Questions?

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In case of questions
Applied Focus: Approaches

- **Structured Decision Making**
  - Formal tools for analyzing decisions

- **Expected Value of Information**
  - Understanding the importance of uncertainty to a decision maker

- **Adaptive Management**
  - Making repeated decisions in the face of uncertainty

Shea et al 2014 *PLOS Biology*
Framework for Structured Decision-Making

- Specify management objective
- Construct alternative models
- Identify possible management actions
- Evaluate expected consequences of interventions under alternative models
- Decide management action

Shea et al 2014 *PLOS Biology*
Expected Value of Perfect Information (EVPI)

- EVPI is the difference between the average of optimum values conditional on each model and the optimum of an average of values, where the expectation is taken over the weights associated with the alternative models.
- Calculates the difference between the expected return if you resolve uncertainty before you make your decision and expected return if you make your decision before (or without) resolving uncertainty.
Adaptive management: AM

A structured decision-making approach to solving dynamic problems that accounts for the value of resolving uncertainty via real-time evaluation of alternative models (Shea et al 2014)

Used in resource management since at least the 1950s

Models as hypotheses

- Alternative models represent hypotheses about the system and its dynamics
- Models are weighted based on their fit to data

Caution:

- Reiner et al. 2013 shows that models may not be independent hypotheses
- If model standards are too proscribed there is no room for innovation
Real-time decision-making during emergency disease outbreaks

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Abstract

In the event of a new infectious disease outbreak, mathematical and simulation models are commonly used to inform policy by evaluating which control strategies will minimize the impact of the epidemic. In the early stages of such outbreaks, substantial parameter uncertainty may limit the ability of models to provide accurate predictions, and policymakers do not have the luxury of waiting for data to alleviate this state of uncertainty. For policymakers, however, it is the selection of the optimal control intervention in the face of uncertainty, rather than accuracy of model predictions, that is the measure of success that counts. We simulate the process of real-time decision-making by fitting an epidemic model to observed, spatially-explicit, infection data at weekly intervals throughout two historical outbreaks of foot-and-mouth disease, UK in 2001 and Miyazaki, Japan in 2010, and compare forward simulations of the impact of switching to an alternative control intervention at the time point in question. These are compared to policy recommendations generated in hindsight using data from the entire outbreak, thereby comparing the best we could have done at the time with the best we could have done in retrospect.
Need for clearly stated objectives

“Control” of a disease:
Need for clearly stated objectives

“Control” of a disease:

- Prevent invasion
- Reduce $R_0$
- Reduce spread rate
- Reduce case load
- Reduce mortality
- Local elimination
- Complete eradication
Why does this matter?

Consider management to ‘control’ an outbreak

(Shea 2004; Shea et al 2010)

e.g., the objective to ‘control spread’ may conflict with the objective to ‘minimize mortality’

...as seen in the 2014 Ebola outbreak