Using experimental design to better understand infectious disease spread in the livestock industries

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Infectious Disease Transmission Models

Goal:
- Build a mathematical model for how disease spreads through some population

Why?
- To help us understand how disease spreads & so how to control it

For example:
- Designing optimal vaccination/culling/surveillance policies
The reported cases show a distinct peak in late March, followed by a long tail from May onwards. Note that the daily cases are stochastic.

The spatial distribution of cases shows large aggregations in Cumbria, Devon and the Welsh borders.

(■ = Culled,  ● = Cases)
Experimental Design

- Infectious disease transmission experiments involve observing disease spread under controlled conditions to help understand characteristics of the disease.
- A typical objective might be to quantify:
  - basic reproductive number ($R_0$)
  - infectious period
  - treatment effects (i.e. compare treatments)
Experimental Design

- But transmission experiments cost money and time
  - animals
  - biosecurity
  - testing
  - technicians

- We always have limited resources
  - How do we best deploy those resources?
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- Use **Experimental Design** (set of statistical techniques)

Design experiment in such a way that it results in data that is as informative as possible (given limited resources)
Simulation, Estimation and Design

INPUT or PARAMETERS → MODEL → OUTPUT or DATA
Simulation, *Estimation* and Design

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**ESTIMATION**
Simulation, Estimation and Design

INPUT or PARAMETERS → MODEL → OUTPUT or DATA

ESTIMATION

DESIGN

What DATA?
Experimental Setup

- Population of 200 animals sorted into 10 isolation units (pens)
- There are thus 20 animals in each pen
- All of the animals within a particular pen will either be treated (e.g. vaccine) or not
- Experimenter will treat animals in 5 randomly chosen pens
Experimental Setup

- One individual from each of pen will be randomly chosen for inoculation with an infectious disease agent and becomes infectious at day 1
- Let experiment run over course of 20 days
- Imagine we have resources to observe disease status of all animals on two days
Experimental Setup

- Statistical Modelling Goal:
  - Identify ‘treatment effect’ from observed ‘disease status data’

- Design Goal:
  - Determine observation days that best enable that modelling goal

Note: there are 171 possible designs for this experiment:

(2, 3), (2, 4), ..., (2, 20)
(3, 4), ..., (3, 20)
...
(19, 20)
Example

- Typical epidemic curves for given model of system

![Graph showing typical epidemic curves for different scenarios.](image-url)
In theory we could run our experiment multiple times in order to work out how to best run it.

Of course, limited resources do not allow this.

However, we can run our experiment on the computer

- Simulate experiment
- “Collect data” for given design
- Quantify the amount of information that data gives us
- Repeat this to compare performance of many design
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3. Identify aspect of the experiment we are most interested in and form a mathematical function to characterize information about that aspect (UTILITY)
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3. Identify aspect of the experiment we are most interested in and form a mathematical function to characterize information about that aspect (UTILITY)
4. For each possible experimental design we could consider, simulate experiments under PRIOR model and find design that maximizes the UTILITY
Here we define a utility concerned with being able to estimate accurately:

the probability that any single animal will be infected from one other infectious animal during one day

given the data we’ve observed.
Ranking Designs

\[ \tau_1 \]

\[ \tau_2 \]
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Discussion

Other design aspects to consider:
- Spatial layout of pens when between-pen spread is possible
- Number of pens/number of animals
- Number of treated versus control pens

Results from such experiments:
- can be fed into herd-level / population-level model
- provide insights into further experiments that can be run
- help inform disease control strategies


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