Verification, validation and sensitivity analysis of disease models

"All models are wrong, but some are useful."

(George Box)

"How wrong does a model have to be before it is useless?"

(Green and Medley, 2002)

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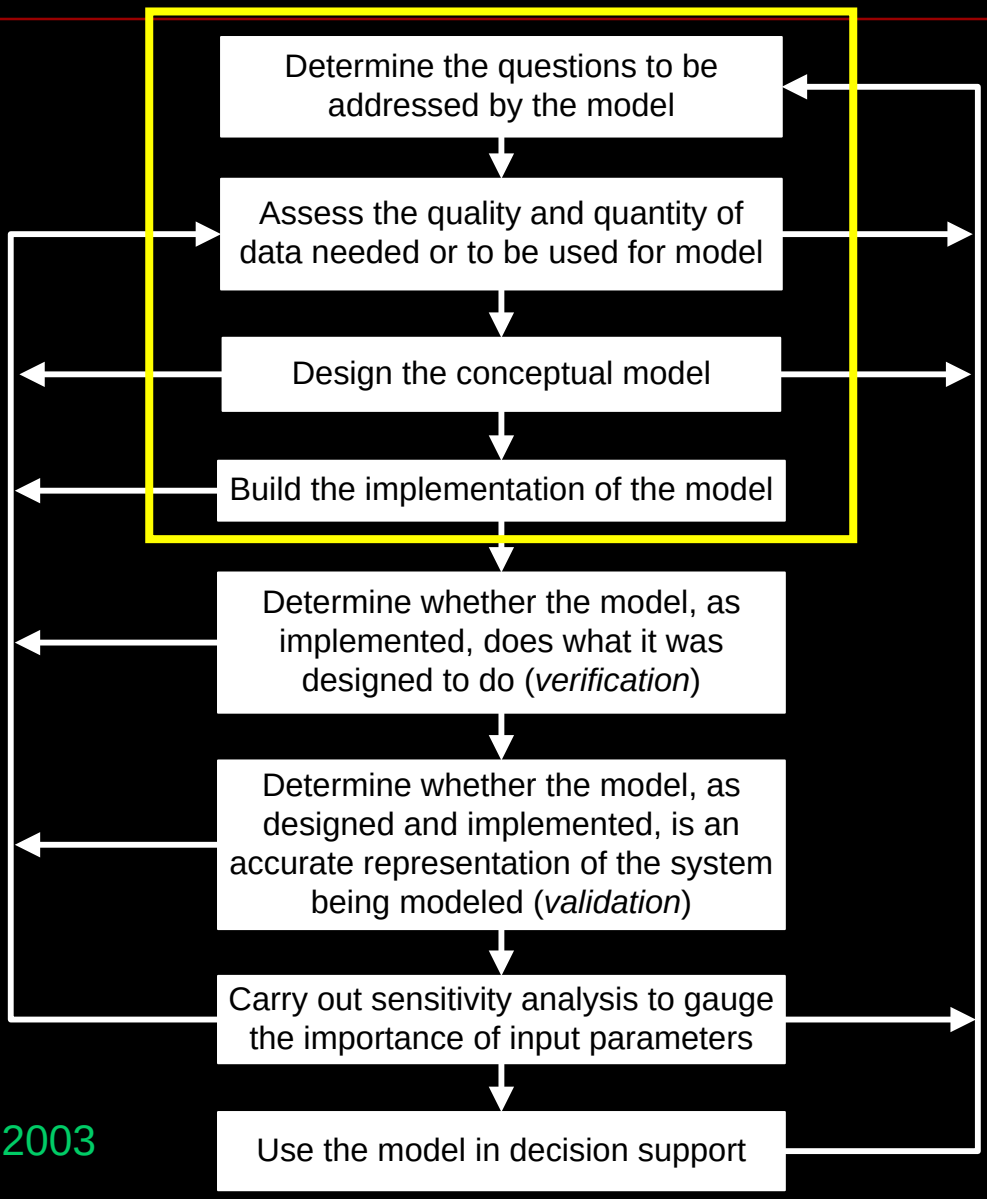
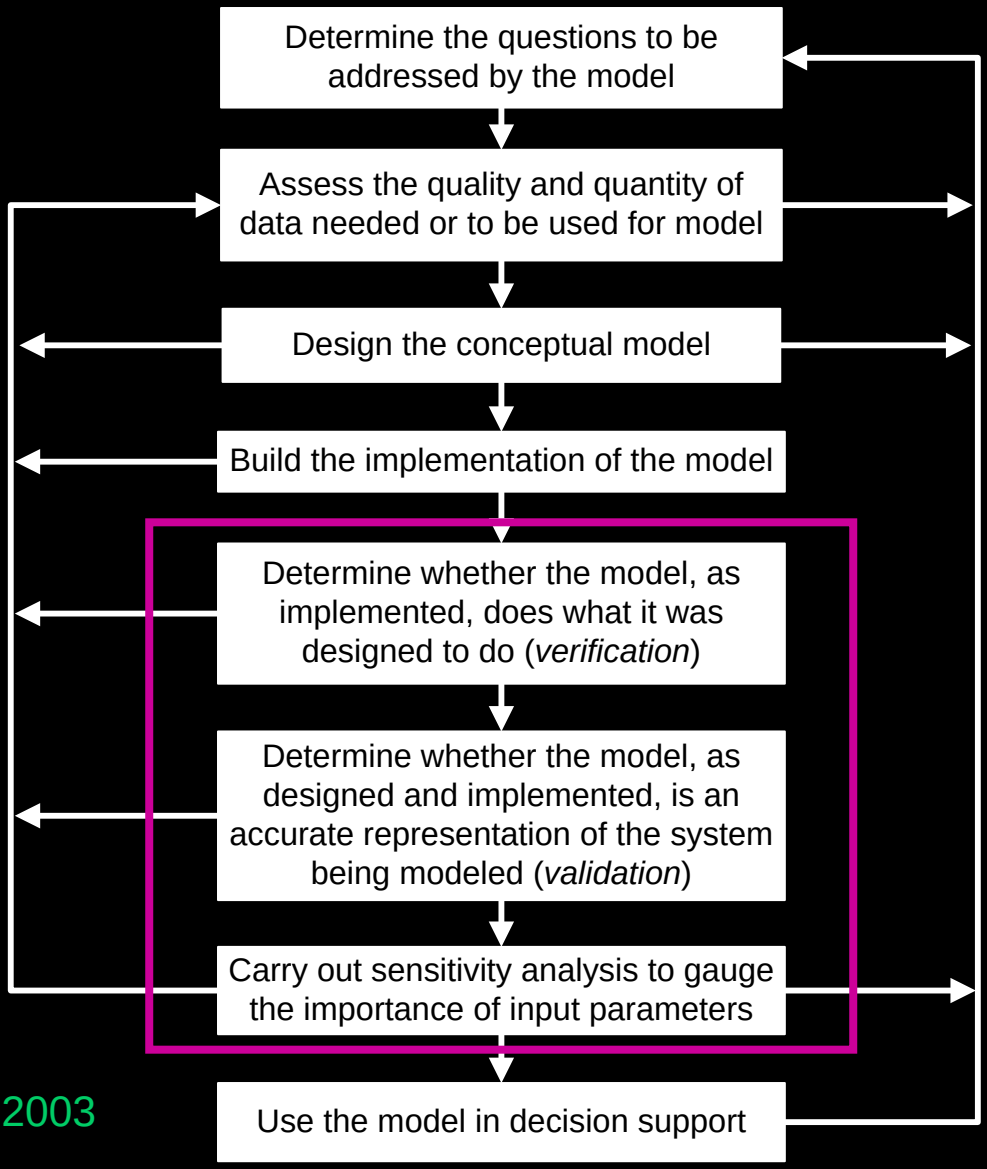
Stages in model building: What we've done



Adapted from Taylor, 2003

Stages in model building: What we still need to do



Adapted from Taylor, 2003

Verification of models

- Does the constructed model conform to the desired conceptual model?
- Is the program working correctly?
- Extensive testing may be necessary, depending on the complexity of the model
- “Hidden” assumptions can be identified through this process

A verification anecdote

- *Question:* What happens if we use *NAADSM* to build a model with very efficient disease detection, but without any specified form of disease control?
- *Answer:* Outbreaks get worse
- While perhaps counterintuitive, this result is "right", based on the *assumptions of the model*
- (But is it a realistic result?)

Verification versus validation

- Validation can be defined as “determining whether the simulation model is an acceptable representation of the real system – given the purpose of the simulation model”[1]
- *Verification*: did you build the model right?[2]
- *Validation*: did you build the right model?[2]

Sargent 1999; Kleijnen 1999

Criteria for model validity (I)

- Does the model mimic actual events?
  - By which measure or measures will this be assessed?
    - Outbreak duration
    - Total number of units affected
    - Rate of disease spread
    - Spatial characteristics of disease spread

Miller, 1976; Taylor, 2003

Criteria for model validity (I½)

- What does “mimic actual events” mean in a Monte Carlo simulation model?
  - Recall that the result of a Monte Carlo simulation is a distribution of possible outcomes, each with different likelihoods
  - The result of a real outbreak is only a single event
  - Is the result of a real outbreak an “average” event, or a “rare” event?

Miller, 1976; Taylor, 2003

Criteria for model validity (II)

- Was the model validated against data not used in its construction?
  - This implies the need for a lot of data
  - In epidemiological systems, especially of livestock or wildlife, available data is limited

Miller, 1976; Taylor, 2003

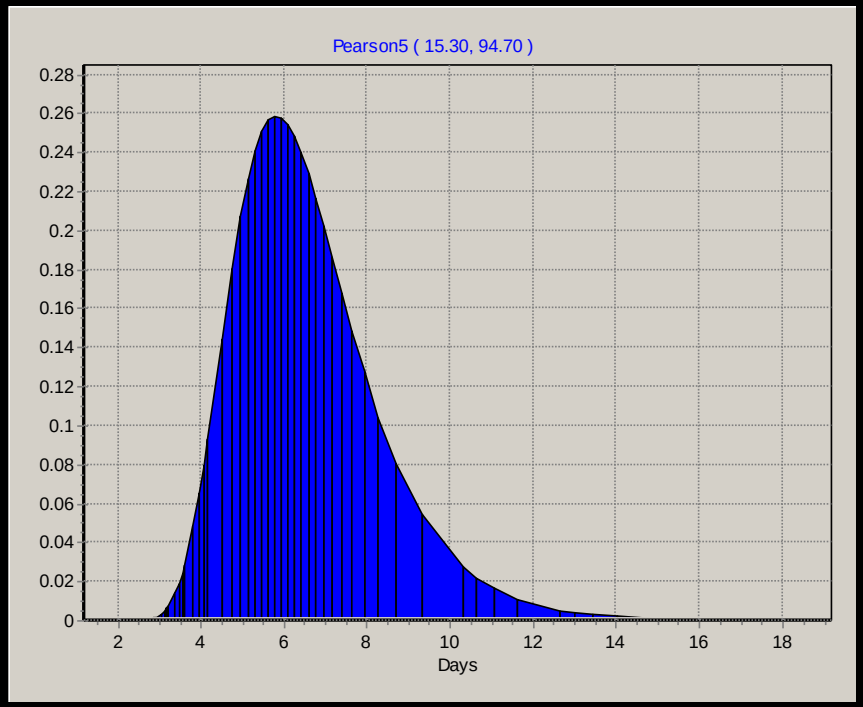
The importance of data in modeling

Epidemiological knowledge	*Data quality and quantity*	
	Poor	*Good*
Poor	• Exploration of hypotheses	• Hypothesis testing
Good	• Simplified representation of past events • Guarded use for prediction of future events	• Detailed representation of past events • Prediction of future events

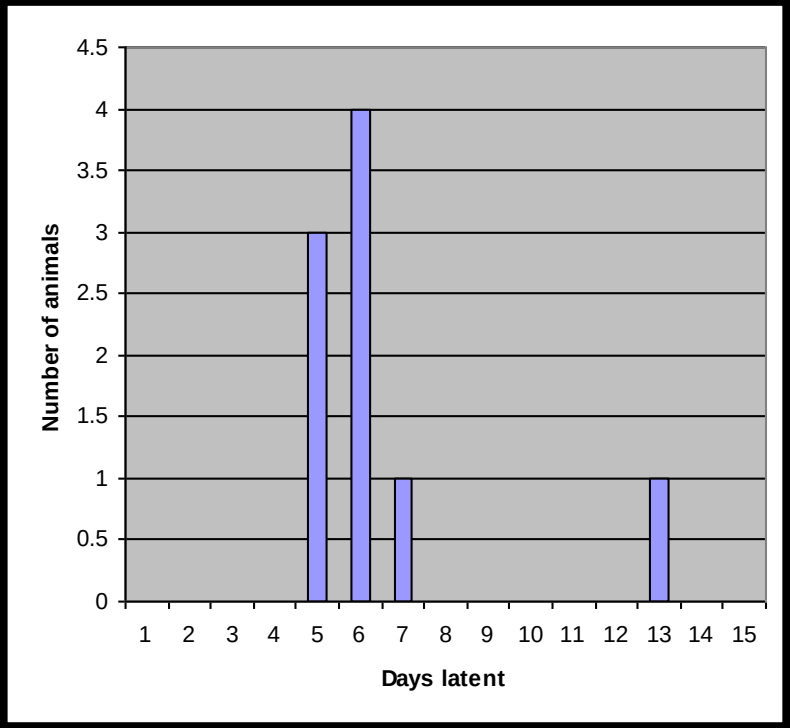
Thrusfield, 2005; Taylor, 2003; Holling, 1978

A data anecdote

- A probability density function for the latent period for FMD in sheep:



- The data used to generate the function:



Bates et al., 2003; Burrows, 1968

Data requirements for achieving "validation"

To assess the accuracy and validity of disease models, "we need more epidemics where [disease] has occurred in similar situations or we need situations where the outbreak was similar but modeling was not used."

(Green and Medley, 2002)

An assertion…

- Based on the criteria suggested above, “validation” of epidemic disease models is not possible
- Is modeling a pointless exercise?
  - Well, no…
- Are there alternative assessments that might be used to assess model validation?

Criteria for model validity (III)

- Does the model make biological sense?
- Does the model fit the use for which they were designed?
- *Sensitivity analysis* should be conducted to assess the influence of uncertain variables

Miller, 1976; Taylor, 2003

Sensitivity analysis (I)

- How much influence do key parameters have on the output of a model?
- Are there parameters for which data is uncertain that influence the output of a model?
- Situations like these might indicate that more attention should be paid to data collection regarding these critical parameters

Sensitivity analysis (II)

- Sensitivity analysis can help to identify thresholds or “tipping points”
  - Do slight changes in particular parameters have a major impact on the outcome of a model?

Sensitivity analysis (III)

"Sensitivity analysis can support validation: such an analysis shows whether factors have effects that agree with experts' prior qualitative knowledge."

(Kleijnen, 1999)

Data and validation, revisited

"Any model ultimately depends for its validity on the accuracy and completeness of the data underpinning it. Close collaboration between the model builders and subject matter experts is important in ensuring that a model is based in reality."

(Taylor, 2003)

References cited

- Bates, T.W., Thurmond, M.C., and Carpenter, T.E., 2003. Description of an epidemic simulation model for use in evaluating strategies to control an outbreak of foot-and-mouth disease. *American Journal of Veterinary Research* 64: 195–204.
- Burrows, R., 1968. Excretion of foot-and-mouth disease virus prior to the development of lesions. *Veterinary Record* 82: 387–388.
- Green, L.E., Medley, G.F., 2002. Mathematical modelling of the foot and mouth disease epidemic of 2001: strengths and weaknesses. *Research in Veterinary Science* 73: 201–205.
- Kleijnen, J.P.C. 1999. Validation of models: Statistical techniques and data availability. Proceedings of the 1999 Winter Simulation Conference.
- Sargent, R.S. 1999. Verification and validation of simulation models. Proceedings of the 1999 Winter Simulation Conference.
- Taylor, N. 2003. Review of the use of models in informing disease control policy development and adjustment. A report for the Department for Environmental, Food, and Rural Affairs, UK. *http://www.defra.gov.uk/science/documents/publications/2003/UseofModelsinDiseaseControlPolicy.pdf*