Appendix 27

Enhancing confidence in epidemiological models of Foot-and-Mouth Disease

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Executive Summary

In the context of a growing need for reliable decision support systems, a survey of current Foot-and-Mouth Disease modelling work was undertaken to assess confidence in current models and identify priorities for future development and data research. There are a number of groups separately developing models, most of which are very similar, focussing closely on vaccination and outbreak control together with logistic and economic implications.

These models are too complex for individual analysis and comparisons between them will assist in improved implementation. This will not, however, validate underlying, often shared, assumptions, so that attempts to replicate known sequences of events remain important even though at present there are insufficient sets of outbreak data for models to be either fully vindicated or invalidated.

Procedures are necessary for the data used in models to be validated and managed, so that it is clear to decision makers what inputs models are based on, and that different models are based on the same agreed data. Integral to this is the ownership of parameters, especially with regard to logistics and available resources. The high levels of uncertainty in many parameters mean that sensitivity analysis, as far as computationally feasible, remains a prerequisite for confidence in output. A gap analysis to consider what experimental results are required for future improvements would be of value.

Greater knowledge of a model by experts is necessary for their assumptions to be assessed and validated. Given the improvements in program accessibility and simulation output, both the potential role of models and their limitations need to continue to be fully appreciated; their scope and purpose, and the involvement of end users, should be clear at inception.

1. Introduction

The modelling of Foot-and-Mouth Disease (FMD) is a continually growing area of research whose importance in the understanding of the epidemiology and control of the disease has been widely acknowledged (Follett, 2002), if sometimes with reservations (Taylor, 2005). The 2001 outbreak in Europe instigated a significant amount of new research, both by reiterating the socio-economic importance of the disease and, no doubt, because of the significant data set recorded in the UK. Such comprehensive data is a prerequisite for many of the models currently in use, and it is utilised widely by researchers (not only in Europe) for the validation and fitting of models. Developments in computing capacity have also allowed such vast data sets to be fully exploited.

The acknowledged preference for the use of emergency vaccination in any control strategy (Anderson, 2002, Follett, 2002) and its inclusion in contingency planning (EUFMD, 2001) has also exacerbated the need for reliable decision support systems. The lack of experimental results for the use of vaccines in a major outbreak, and of equivalent data sets to the 2001 UK outbreak, means that their deployment will rely heavily on theoretical predictions. Following detailed critiques (e.g. Kitching et al., 2005, Taylor, 2005) there now exists a clear understanding of, and a good level of agreement about, the key factors any model of FMD should include.

A study of current work was undertaken to consider strategies for improving confidence in FMD modelling. By considering the similarities and differences between models and the questions they attempt to answer we have sought to identify common criticisms in the systems currently available and potential areas for development.

Although overviews, reviews and critiques of existing models appear regularly in the literature (Morris et al., 2001, Green and Medley, 2002, Kao, 2002, Moutou and Durand, 2002, Kostova, 2004, Perez et al., 2004, Bronsvoort, 2005, Keeling, 2005, Taylor, 2005, Murray, 2006), albeit often with a strong focus on the 2001 UK outbreak, there appears to be a significant amount of on-going work which has not yet been published: for example, the development of an FMD model (Backer, 2007) based on a model for classical swine fever using a within-pen, within-herd and between-herd structure (Backer et al., 2007).

Thus, while this survey has included all the publicly active models, the author accepts that the list of research groups mentioned may not be comprehensive.

2. Methods

A literature survey of published FMD models was undertaken, together with an internet search for on-going research and groups active in this area. Clarification was sought directly from corresponding authors and project leaders via email where necessary. Only epidemiological models currently being applied or developed are discussed here: many more exist (see for example Kostova, 2004, Taylor, 2005, Keeling, 2005 and references therein). Systems which would form only part of an epidemiological model – such as advanced atmospheric dispersion models (e.g. Carruthers et al., 1996, Galmarini et al., 2004, Thykier-Nielsen et al., 2004) – and which are not specifically focused on FMD, or have not been integrated into a model, are also not included.

3. Results

A number of separate models of FMD epidemiology were identified: a summary of those considered is given in Table 1.
Most current models are stochastic Monte-Carlo species-specific spatial farm-based state-transition micro-simulations based on the SIR paradigm. The Imperial model stands alone in being deterministic and not spatially explicit.
Recent models have been primarily focused on the use of vaccination in the event of an outbreak, in conjunction with other methods of control including movement restrictions, security zones, slaughter of dangerous contacts and contiguous and pre-emptive culling. Most now also include response logistics, allowing the cost-benefit associated with different strategies to be assessed.

All current FMD models are highly complex, resulting in a lack of transparency: published papers provide, at best, a basic description of the system but rarely enough for it to be reproduced by others. The replication of such work is, in practice, impractical anyway, but public access to comprehensive details of all aspects of models is necessary if confidence in their structure, at least, if not their execution, is to be established.
Micro-simulations such as AusSpread, Exodis and InterSpread Plus provide detailed models of different mechanism to include all known or suspected forms of transmission, including fomites and airborne spread, but therefore need to estimate a significant number of unknown parameters for which they rely heavily on "expert opinion". Thus, even where details of the simulation protocol and the parameter values used are available, it is not possible to make an objective assessment of their accuracy. Because of this lack of reliable data other models, such as the Imperial and Keeling models, use crude descriptions of transmission based on distance kernels fitted to outbreak data. Such a process inevitably results in the model becoming dependent on a particular scenario and casts doubt on its accuracy under different circumstances (although this criticism can equally be applied to expert opinion in more complex models which may also be based on specific situations). At present no model combines spatial spread with adequate intra-herd dynamics modelling, probably due to exiguous experimental data.

There is a clear need to include and/or improve the modelling of within-farm dynamics (Keeling, 2005) but this requires new data on transmission: otherwise a more complex model may simply introduce artifacts not there in current farm-based models. How within-herd spread is modelled significantly influences the macroscopic dynamics of the system: a comparison project of models found that increasing infectivity results in significantly fewer infections than a constant infectivity with the same average (Dubé et al., 2006, Dubé et al., 2007), but at present the models of these processes remain hypothetical.

Each of the spatial models is capable of using detailed input data concerning farm locations and size, but weaknesses in the farm data provided constrain the reliability of results. It is reasonable to require the accuracy of inputs such as herd sizes and locations or contact histories to be of an order of magnitude greater than the desired outputs. Developments mean future models are likely to consider even more transmission factors including biosecurity, topography and complex airborne spread. The inclusion of these will, however, be questionable at best if adequate data cannot be provided to support their explicit modelling. At present significant effort has been focused on providing adequate logistics modelling, to incorporate resource constraints into simulated control scenarios, which again requires accurate and up to date regional or national data.

In all cases “it remains an open question whether the local-scale inaccuracies present in the models are sufficient to invalidate any of the national-scale predictions” (Keeling, 2005).

Models produced for or by specific end-users are being developed to be user-friendly, with easily accessible interfaces and graphical outputs. While this greatly facilitates their use by resource managers and economists as well as epidemiologists, there exists the potential for misuse and misinterpretation of self-generated simplistic quantitative results. Thus whether a model is fit for purpose is now becoming a question of implementation as well as construction.

Table 1: Status summary of known FMD models currently being applied or under development.

Model	Owners/Developers	Summary	Application
Automota (no official name established)	Texas A&M University College of Veterinary Medicine & Biomedical Sciences, USA & University of New South Wales, `Australia.	A two-species geographical-automata (Ward et al., 2007) developed from a cellular automata (Doran and Laffan, 2005) with probabilistic inter-herd-distance dependent transmission. This model is particularly suited to FMD in wild animals or situations where flocks or herds are widely dispersed, focusing as it does on spatial herd location and allowing for implicit herd movement, and may be extend to multiple species in the future (Laffan, 2007).	Simulation of hypothetical FMD spread within feral pig, deer and cattle in southern Texas, USA, based on 2004 Department of Agricultural National Agricultural Statistics Service data, Department of Agricultural Natural Resources Conservation Service Ecological Site (Range) Descriptions and land-use data and ecological site carrying capacity from expert opinion.
AusSpread	Department of Agriculture, Fisheries and Forestry, Australia.	A stochastic Monte-Carlo species-specific spatial farm-based state-transition micro-simulation accommodates real farm boundaries or point location data, developed for the Australian setting (Garner and Beckett, 2005). DAFF is in the process of entering into a collaborative arrangement with the Commonwealth Scientific and Industrial Research Organisation (CSIRO), to develop and validate a whole-of-country model for FMD, based on a National Livestock Movement Model (NLMM) due to be completed May 2008. Plans include the incorporation of logistics and additional spatial layers such as roads, waterways and wildlife.	Designed to be user-friendly. Simulation of hypothetical FMD outbreak in Southern Queensland (Garner and Beckett, 2005). Part of a comparison project run by the Quadrilateral countries in 2005 together with InterSpread Plus and NAADSM (Dubé et al., 2006, Dubé et al., 2007).

Model	**Owners/Developers**	**Summary**	**Application**
UCDavis (no official name established)	University of California, USA.	A stochastic Monte-Carlo species-specific spatial farm-based state-transition micro-simulation model (Bates et al., 2003b).	Simulation of a hypothetical FMD epidemic in California, USA to predict disease spread (Bates et al., 2003c) and cost-benefit of vaccination (Bates et al., 2003a) using estimates based on 1997 USDA Agriculture Census data.
		A stochastic intra-herd disease spread model (Carpenter et al., 2004) based on the Reed–Frost equation.	Simulation of spread of FMD within a hypothetical 1,000-cow dairy herd in California.
		Currently no published work combines the above two models for intra- and inter-herd dynamics.	Modelling research within the group is ongoing, looking at FMD in the US and globally, as part of a wider surveillance and prediction programme (Carpenter, 2007).
Exodis	Risk Solutions for Department of the Environment, Farming and Rural Affairs, UK.	A stochastic Monte-Carlo species-specific spatial farm-based state-transition micro-simulation model with distance-dependent transmission and some intra-farm disease dynamics, consisting of an epidemiological model (Risk-Solutions, 2005c) together with an economic component (Risk-Solutions, 2005b), which has been used for cost-benefit analysis (Risk-Solutions, 2005a) and more recently to study the impact of electronic identification of sheep on control (Risk-Solutions, 2006).	Designed to be user-friendly and to be implemented as Defra's in-house model during 2007. The currently planned training of users aims to impart expert knowledge of the program to build confidence and aid improvement and development.

Model	Owners/Developers	Summary	Application
Imperial (no official name established)	Imperial College, UK.	A deterministic differential model (Ferguson et al., 2001a, Ferguson et al., 2001b) with a strong focus on the distribution of temporal delays between infection, reporting and slaughtering of herds rather than detailed mechanisms designed for robust and rapid parameterisation. Differentiates between long and short range transmissions but is not spatially explicit, making the modelling of dangerous contact and contiguous culling difficult. Substantially refined since 2001 (Keeling, 2005).	Used for prediction of temporal dynamics of 2001 UK outbreak, with parameterisation based on a spatially explicit statistical model applied regionally using contact-tracing and 2001 census data (Ferguson et al., 2001a, Ferguson et al., 2001b).
InterSpread Plus	EpiCentre, Massey University, New Zealand.	A stochastic Monte-Carlo species-specific spatial farm-based state-transition micro-simulation model incorporating a variety of distance-dependent and logistics transmission mechanism, InterSpread Plus (Stevenson et al., 2006) is a development of the original InterSpread model (Sanson, 1993, Sanson et al., 1994, Morris et al., 2001). Widely used as it is not disease specific and capable of including logistic modules, but requires a large amount of disease-management data and parameters based on expert opinion. Simulation framework software (but not FMD specific modelling and parameterisation) is free available (Epicenter-team, 2007).	Used for prediction of dynamics of 2001 UK outbreak using contact-tracing and 2001 census data (Morris et al., 2001). Simulation to replicate 2002 outbreak in Korea and explore alternative strategies (Yoon et al., 2006). Simulation of hypothetical scenarios in Switzerland to examine the effectiveness of the current Swiss FMD control measures (Bachmann et al., 2005). Part of a comparison project run by the Quadrilateral countries in 2005 together with AusSpread and NAADSM (Dubé et al., 2006, Dubé et al., 2007).

Model	Owners/Developers	Summary	Application
Keeling Also referred to as the Edinburgh/ Cambridge model or Warwick model (no official name established)	Warwick University, Edinburgh University & Cambridge University, UK	A stochastic Monte-Carlo species-specific spatial farm-based state-transition simulation model with distance-based transmission based purely on farm susceptibility and infectiousness (compounded by herd size) parameterised from contact tracing data (Keeling et al., 2001, Keeling, 2005). Focussing on spatial structure the model has fewer parameters than those with more complex transmission descriptions (on the grounds of insufficient reliable data) allowing for relatively fast simulation. No explicit modelling of logistics. Model results are highly stochastic suggesting epidemics are highly variable and making local scale predictions difficult (Keeling, 2007).	Used for prediction of dynamics of 2001 UK outbreak using contact-tracing and 2001 census data (Keeling et al., 2001). Developed to consider vaccination in the UK (Keeling et al., 2003) and then extended to model different vaccination strategies (Tildesley et al., 2006). Adapted by others to consider if vaccinated farms have carriers(Arnold et al., 2007) Currently model being developed for and applied to Denmark and USA (Keeling, 2007).
MESA	Lawrence Livermore National Laboratory for Department of Homeland Security, USA.	Multiscale Epidemiological/Economic Simulation and Analysis is a large-scale (US scale) decision support system to evaluate the consequences of Foot-and-Mouth disease introduction to USA. Resulting in part from a gap-analysis (Kostova, 2004), it is likely to be a micro-simulation model employing large scale computing similar to and potentially based on the UCDavis model.	Details are currently not publicly available but the group claims significant progress in its development (Kostova, 2007).

Model	Owners/Developers	Summary	Application
NAADSM	Canadian Food Inspection Agency, Canada, United States Department of Agriculture, USA, Ontario Ministry of Agriculture and Food, Canada, Colorado State University, USA, & University of Guelph, Canada.	A stochastic Monte-Carlo species-specific spatial farm-based state-transition micro-simulation model with distinct transmission mechanisms, the North American Animal Disease Spread Model (NAADSM-project-team, 2006, Harvey et al., 2006), an enhanced version of the SpreadModel (Schoenbaum and Disney, 2003) which was motivated by an Australia model (Garner and Lack, 1995). A project to combine this with a wind-dispersion model and a logistics module, the Foreign Animal Disease Emergency Response System (FADERS) is due for completion in 2010 (Dubé and Roy, 2005, Dubé, 2007).	Freely available software designed to be user-friendly. Part of a comparison project run by the Quadrilateral countries in 2005 together with InterSpread Plus and AusSpread (Dubé et al., 2006, Dubé et al., 2007). Being used to develop a bank of FMD outbreak scenarios and also for vaccination simulation exercises of USA and Ontario, Canada (Dubé, 2004, Dubé, 2007). Used by others groups to consider, for example, a hypothetical outbreak in Kansas (Pendell, 2006).

4. Discussion & conclusions

The complexity of most currently used models make it unfeasible for the methodology to be replicated by other groups (Keeling, 2005), and also makes the robustness of conclusions difficult to assess.

One approach recently used by the Quadrilateral countries (QUADs: Australia, Canada, New Zealand and USA) was a comparison project considering various different scenarios using InterSpread Plus, AusSpread and NAADSM. This was the first such exercise of its kind and helped highlight modelling assumptions and programming protocols, resulting in improvements in all of the participating models (Dubé et al., 2006). Results were not found to be significantly different at the level of policy (Dubé et al., 2007), which was also felt to give credence to the models used. It must be noted, however, that all these models are very similar with fundamentally the same structure: thus, while such comparisons may improve and help develop "best practice" amongst such models – which is, of course, valuable in itself - it does not help prove that they are "good enough". Reviews of the three main models used during the 2001 UK outbreak (the Imperial model, the Keeling model and InterSpread) also found that, despite the more significant technical differences between them, their predictions of the required control methods were similar (Keeling, 2005). Yet strong criticisms have been levied at the accuracy of these results despite their consistency (see for example Haywood and Haywood, 2002, Taylor, 2005, Kitching et al., 2006).
A similar project has been carried out by EpiLab in Denmark (Milne and Ersbøll, 2004), comparing InterSpread, the UCDavis model and the Keeling model, with results in progress (Dubé, 2007).
The pragmatic approach in model comparisons is to use the lowest common denominator for all models, that is, to only attempt to consider those situations and inputs which all models can handle. This is useful in verifying the models but has the disadvantage that individual models are prevented from performing at their best, and prevents certain modelling assumptions from being validated. While such a process is a useful and necessary step, part of any complete comparison programme should be consideration of difficult and/or realistic scenarios and data sets without an *a priori* assessment of what each models can handle and how they do so. This would further highlight differences between models, although without necessarily indicating which is better.

Underlying flaws in input data may result in consistent but erroneous advice: for example, the contact tracing data produced for the 2001 has been heavily criticised for producing over-estimates of infectivity in the models used (Kitching et al., 2006), since direct contacts which are omitted require models to explain infections through other – usually proximity based - means of transmission. The critical evaluation of data supplied to modellers is integral to the evaluation of output: it may be helpful on a national level to consolidate data (concerning current levels of resources, logistical constraints, disease characteristics etc.) and to develop protocols for its regular reviewing and updating. Access to such information could then be provided to modellers, ensuring that all advice received is based on known and agreed data.

Validation of models may be sought by attempting to reproduce real life events: such an exercise will be undertaken at the Institute for Animal Health, Pirbright, in June 2007, where the meteorological dispersion models of a number of different nations will be used to consider airborne spread of FMD (Gloster, 2007). While replication can be valuable, confidence may be misplaced in potentially deceptively realistic outputs. Firstly, most models are initialised and parameterised by using known information from an outbreak, and so the desired output is used as input. Transmission kernels, for example, have been fitted using the known spread of FMD in the UK in 2001, with model predictions then only compared to that outbreak. Confidence in these models should require the replication of one outbreak having been parameterised with data from another. Although the 2001 UK data set contains a number of distinct regional outbreaks, these have not been used to cross-fit simulations and are sometimes analysed separately because of their significant differences (e.g. Kao, 2001, Savill et al., 2006).
Unfortunately no comparable data sets are freely available, and it is therefore difficult to tell how suitable the 2001 UK outbreak really is: it could, for example, have followed a particularly unlikely course which an accurate model would predict as possible but improbable. Certain model results appear highly stochastic (Keeling, 2007), suggesting that epidemics will also be highly variable.
Data from the 2001 Uruguay outbreak, during which vaccination was used for control, is currently being used to validate the NAADSM model (Dubé, 2007): the data is apparently of good quality but is not publicly available for use by other groups. Similarly there is also potentially good but tightly controlled data from other South American countries, such as that from Argentina now being studied using InterSpread.

Finally, the current focus on vaccination strategies means that all models are attempting to make predictions about situations of which we have very little experience; while this is the very power of mathematical modelling which is desired, the further hypothetical scenarios venture from what is known historically (in terms of logistics, vaccination, serotype etc.) the harder it is to validate results. Explicit modelling of spread in endemic countries has not been carried out, although spatial distribution of the disease in Pakistan was recently estimated using statistical analyses (Perez et al., 2006), and at present it is unclear what the study of vaccination in such different settings would reveal.

Confidence in the underlying model structure and parameters used can only be achieved through a detailed understanding of the system. Defra is currently implementing a training programme so that experts within the department can use the Exodis program with a thorough knowledge of its structure and assumptions. This appears a pragmatic form of peer review, with specialists in different spheres assessing different aspects of the model, not just the output.

Integrated with this is the responsibility for parameter validation, which still depends considerably on "expert opinion" for these large systems. It remains clear that continued research into transmission and vaccination (including immunity response, challenge response prior to full immunity, response to heterologous challenge and the carrier potential of vaccinated animals), as well as systematic collection and organisation of data (concerning resource etc), remains a priority.

All models have undergone some level of sensitivity analysis, whereby parameters whose value is not certain are varied and the effect on results examined. Such a process is only mathematically rigorous, however, if all parameters are allowed to take on any of their possible/reasonable values simultaneously: this is usually computationally unfeasible, and in practice only small subsets of parameters are tested together. This is sufficient to help promote confidence in results, but only if it is done systematically and openly.

Finally, the reliability of modelling advice now depends, more than ever, on the end user. The development of a number of user-friendly systems allows for the simulation of results with little knowledge of the underlying model.

The strength of this is that experts in one field, such as resource planners, can investigate potential scenarios without a detailed knowledge of epidemiology, for example. There is a danger, however, that convincing output – including automatically generated and easily interpretable geographical plots and summary charts - may be generated from quite unrealistic input. Thus it is strongly encouraged that sufficient training be given to all operators of such systems: at present Defra aims for all expert users to be knowledgeable in all aspects of the model to a reasonably high level.

Despite the inclusion of detailed individual farm level data, all models remain of only strategic value. Detailed modelling of local scale events is provided to give the most accurate representation possible of the overall situation, but cannot provide advice to the same extent. Most models, for which ever country they have been designed, attempted to provide regional guidance, but never at the tactical level. This has been emphasised by all model developers: NAADSM for example states it is not intended for outbreak predictions; AusSpread is advocated as a training and investigation tool with only limited scale-dependent forecasting. As well as continuing to question modellers' assertions, it is also important to heed their reservations, since the theoretical step from peacetime policy formulation to outbreak planning and decision making is significant, even if it appears technically simple.

The scope and purpose of any future developments or new models should be clear at the outset, so that end-users are involved at inception. Availability and quality of data will continue to remain an integral factor, since these will affect - as much as the validity and implementation of any theoretical construct – the potential use of models.

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6. Glossary

Automaton:	(*pl:* -a) a self-operating machine or mechanism that has been programmed to perform specific actions in a manner imitative of a human or animal.
Deterministic:	a system in which randomness is excluded from the process so that identical inputs will always produce a unique output.
Differential:	based upon differential equations, where relationships involving the rates of change of continuously varying quantities are described through mathematical functions
Micro-simulation:	a computer-generated system to represent the dynamic responses and behaviour of a real-life system, in which individual behaviour is modelled to infer group dynamics.
Monte-Carlo:	a probabilistic technique in which simulations are repeated with statistical sampling applied to undetermined parameters.
State-transition:	a system in which entities can only exist in a discrete number of states, and modelling focuses on how they change between these.
SIR:	paradigm model of epidemiology where individuals in a population can be in one of three states: susceptible (S), infectious (I) and recovered (R); derivative models including additional classes e.g. immunised, carriers.
Stochastic:	involving chance or probability.
Strategic:	part of a long term plan of action designed to achieve a particular goal.
Tactical:	using whatever means are available to achieve ends (often a temporary and/or limited advantage) that are at a smaller level and of less long-term significance than strategic goals.

Recommendations for
Enhancing confidence in epidemiological models of Foot-and-Mouth Disease

David Schley

Detailed models too complex for exhaustive analysis should be compared with each other.

- This does not validate the underlying modelling assumptions but is a necessary step in model verification, improving implementation and helping develop best practice amongst similar systems.
- This should be part of a wider communication process between groups to disseminate ideas and develop mutual understanding of models.
- The role of smaller scale sub-models, easier to validate and useful for examining specific issues, should be acknowledged.

Model simulations should be compared to known events for comparison.

- Lack of good data from outbreaks in non-vaccinating FMD-free countries means that models are being parameterised using the same data that they are trying to replicate.
- Given the stochastic nature of outbreaks, individual events may be quite unlikely and thus predicted as improbably by an accurate model: without sufficient distinct sets models cannot be invalidated by their failure to replicate historic events alone.

Greater access should be provided to available epidemiological and control data.

- Access to outbreak data in endemic countries is often tightly controlled, so that most groups cannot utilise it in the development of their models.
- Provision of a clear protocol for the dissemination of data to researchers both in peace-time and during an outbreak would be useful.

Knowledge of a model and its assumptions should be cultivated amongst experts and end users.

- Pragmatic peer review of model assumptions and structure is necessary in order to assess their validity.
- The development of easily accessible models producing more sophisticated outputs means it is important that the role of models, their limitations and the quality of the data they use continues to be fully appreciated
- Integral to this is the ownership of parameters (especially with regard to logistics and available resources) by the relevant departments.

Procedures for the data used in models to be validated and managed should be implemented.

- It must be clear to decision makers what information has been used in a model.
- Different models should be based on the same (inter)nationally agreed best available data.

A gap analysis of model input data requirements should be carried out.

- This should include explicit details by all national bodies of the farm, resource etc. data available, together with an evaluation of its quality.
- National and regional differences in farming practice and structure should be detailed in order for models to be suitably modified.

A gap analysis of experimental data requirements should be carried out.

- Successful modelling of complex scenarios will require accurate parameterisation of, and therefore the acquisition of experimental data on, virus transmission and vaccination (including immune response, heterologous challenge and serotype specific dynamics).
- This information will allow for the development of accurate local models which may be incorporated as sub-systems into larger national-scale decision support tools.

Modellers should provide detailed sensitivity analysis of results.

- It must be clear, especially at the advice level, what changes can be produced by reasonable variations in parameters (whose precise values are not known).

The potential for developing a template model-validation process, involving modellers, veterinarians and policy makers should be considered. A combination of the current Defra exercise for implementing its in-house model Exodis and the Quadrilateral countries' recent comparison workshop is a candidate for this.