Review of EuFMDiS

a European Foot-and-Mouth-Disease Spread model

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Summary

EuFMDiS is a detailed simulation model that explicitly models within-herd and between-herd transmission of FMD, contributing to an intuitive understanding of the model by the user. The model can be used to evaluate different control strategies, varying from the minimal requirements given by EU legislation to ring culling and vaccination, while also considering limited availability of resources. As such, EuFMDiS can be of great help in contingency planning. Considering the multitude of parameters that can be changed in EuFMDiS, we recommend the support of trained epidemiologists when deploying the model to evaluate FMD outbreak scenarios and control strategies. EuFMDiS is a data demanding simulation model which uses many parameters for the different phases of the disease transmission and control processes. Some of these parameters lack biological or veterinary observations for parameterization. As a consequence, input into EuFMDiS relies to a large extent on expert opinion. We conclude that default parameter values in EuFMDiS need to be chosen carefully and supported by scientific literature when available. This applies especially to disease transmission parameters that are uniform over countries and regions. The current overview of default parameter values in the EuFMDiS user manual is lacking completeness and justification. We recommend to provide a summary of input parameter values reviewed from the literature as an appendix to the manual. Furthermore, we strongly advise to evaluate the impact of uncertain input parameters on model results in an extensive sensitivity analysis.

1 Scope and objectives of the review

1.1. Background

The European Commission for the Control of Foot-and-Mouth Disease (EuFMD) has developed the "European Foot-and-Mouth Disease Spread Model – EuFMDiS" to assist countries with improving or testing their preparedness for controlling FMD-outbreaks. EuFMDiS is a derivative from the AADIS model (Bradhurst et al., 2015; 2016) and has been modified and adapted to the European situation to serve as a multi-country European FMD model to improve contingency planning by Member States and at the European level. EuFMDiS has been developed in collaboration with seven pilot countries in South-East Europe (Austria, Bulgaria, Croatia, Hungary, Italy, Romania, Slovenia) and has been prototyped for these countries. In addition, Spain and the Republic of Ireland are currently working on the collection of data to adapt the model to their national context and some other countries such as France have expressed their intention to join EuFMDiS. Before releasing the model for wider use, FAO considers it important that the prototype is reviewed by external experts to evaluate its quality/fit for purpose.

1.2. Terms of reference

Wageningen Bioveterinary Research was asked to perform a desktop review of the EuFMDiS model that addresses the following issues:

1. Conceptual approach
    a. Are the biology and epidemiology of FMD adequately represented in EuFMDiS given the intended use of the model?
    b. Are the control measures represented in the model consistent with European policies and approaches?

2. Modelling approach
    a. Are the approaches used to represent key processes in the model (including disease transmission and disease control) reasonable, given the intended use of the model?
    b. Are the structure, logic, and mathematical representations of these processes in EuFMDiS appropriate and technically valid?
    c. Are the key assumptions made in the modelling approach plausible?

3. Data sources and parameterization
    a. Are the data used in the model suitable and consistent with the modelling requirements and its intended use?
    b. For data supplied by participating countries are the reporting templates and instructions sufficiently clear?
    c. Are there additional data sources that could be used to support the model parameterization?

4. Model outputs
    a. Does the model produce sensible outputs i.e. do they make biological sense based on general understanding and previous experience with FMD in Europe?
    b. Are the outputs appropriate and sufficiently accurate to support the sorts of analyses required given the model's intended use?

2 Activities implemented by the review team

First, the EuFMDiS model was presented to the review team by Koen Mintiens (FAO) at a kick-off meeting. After this meeting, the review team was given detailed documentation on EuFMDiS and some background information. Documents provided to the review team included:

- PowerPoint presentation introducing EuFMDiS
- EuFMDiS user manual
- EuFMDiS key assumptions
- Publication explaining the modelling approach
- Data requirements document
- Data templates with instructions
- PowerPoint presentation explaining the data needs as presented during a workshop in North Macedonia

The review team carefully read the EuFMDiS user manual and publications on AADIS (Bradhurst et al., 2015; 2016) and reviewed the key assumptions and data requirements of EuFMDiS.

The review team also received all necessary files to install the EuFMDiS model to further explore the model and generate results. The instructions for installation of EuFMDiS provided

in the User Manual are largely self-explanatory. However, installation is not an easy task for lay persons as the user has, e.g., to manually configure some text files and share folders. The review team experienced problems in installing the program, most likely because the first zip file that was received had some missing or corrupt files. FAO kindly provided support to accomplish the installation.

The review team explored the demo version of the EuFMDiS model by following the steps of the tutorial in the EuFMDiS user manual. Several scenarios were run with the model, with FMD outbreaks starting at different farm types and in different regions/countries. Also, the impact of changing control strategies to include either ring culling or vaccination was evaluated.

3 Results

3.1. Conceptual approach

EuFMDiS simulates foot-and-mouth disease (FMD) outbreaks in seven EU member states. The model considers different herd types with FMD susceptible animals to simulate both within-herd and between-herd transmission of the disease. Herd types are characterized by region to take into account regional differences within countries. EuFMDiS takes into account the most important between-herd spread mechanisms of the disease, including animal movements; indirect contacts via products, humans or non-animate objects (often referred to as fomites); and airborne transmission. The model also accounts for distance-related spread of which the underlying mechanisms are poorly understood (in the model referred to as local spread). Built-in control measures in EuFMDiS cover the main control measures, both compulsory and optional, as given in EU legislation. We recommend to select only the minimal requirements for control in the default settings of the model (i.e. no national standstill; protection zone of 3 km; surveillance zone of 10 km). An overview of the main control measures of EU Directive 2003/85 is given in Appendix B.

EuFMDiS is a very detailed simulation model explicitly modelling FMD transmission mechanisms. This contributes to an intuitive understanding of the model by the user. However, the vast number of details in EuFMDiS results in many input parameters that need to be parameterized before the model can be run. Parameterization was partly done by the model developers (e.g. within-herd transmission, airborne spread) and partly by the member states (e.g. herds and holdings, animal movements, indirect contacts). For some parameters, biological or veterinary observations required for parameterization are not available, e.g.

indirect contacts and biosecurity levels on farms. Quantification of these parameters is based on expert opinion and cannot be validated. However, validation of model input for parameters for which experimental and/or field data are available is also lacking. Especially the input parameters for the equation based model (EBM) need to be more carefully chosen and supported by references. We consider this a task of the model development team and not the end user.

3.2. Modelling approach

The modelling approach of EuFMDiS is similar to the approach used in AADIS, which is described by Bradhurst et al. (2016). EuFMDiS uses detailed model representations of between-herd transmission routes, including: direct contact (i.e. movement of live animals between herds), movements on and off markets/sale yards; indirect contact (defined as movement of animal products, by-products or inanimate objects between herds); local (distance-based) contact; airborne transmission. In modelling the spread via indirect contact routes, the authors take into account infectivity of the source herd (depending on species and size), susceptibility of the destination herd, and biosecurity measures in place at the destination herds, amongst other factors. The problems with choosing such an approach have been well described in a review of models used for FMD spread during the 2001 epidemic in Great Britain by Keeling (2005). Discussing the InterSpread FMD model that uses a similarly detailed approach for between-herd transmission, Keeling explains: 'The vast number of mechanisms through which infection can be spread is both a strength and a weakness of InterSpread. Complex models have an intuitive appeal and are frequently considered better and more accurate. However, a model is only as good as the data that are used to parameterize it, and complex models require more parameters.' Keeling warns: 'InterSpread includes the effects of a vast number of details that the other models used during 2001 ignored; however, these extra details must be weighed against difficulties in parameterization (which quantifies the effects of observable characteristics on the epidemic process), with expert opinion being required to estimate many important quantities.' Similar remarks were already made by Kao (2002) in an earlier review of the 2001 FMD models. The very same warning applies to EuFMDiS.

Clearly, the structure of EuFMDiS is flexible in the sense that the model can in principle be simplified by switching off transmission pathways and control measures, or by setting certain parameters equal to zero. From that perspective, just as InterSpread, the model is 'more of a framework within which a model can be specified, rather than actually being a model itself. It

is capable of simulating a variety of models and model assumptions, from very simple spatial models to very complex ones' (Keeling, 2005). However, for the user of this framework to make a good choice of model complexity, he/she would need considerable epidemiological expertise. More likely, a typical user would start out from the default parameter values implemented, which in majority have not been validated. Validation of many of these parameters is in fact impossible as the quantitative biological or veterinary observations required for it are missing.

EuFMDiS uses a hybrid modelling approach consisting of a deterministic EBM to simulate within-herd transmission of FMD and a stochastic agent based model (ABM) to simulate between-herd transmission. EuFMDiS accounts for different pathways for between-herd transmission including local spread, direct contacts, indirect contacts, airborne transmission and assembly centres. The last pathway is only used to simulate spread of disease between countries. Pathways for between-herd transmission can be switched on and off by the user, which we consider an asset of EuFMDiS. The use of a deterministic EBM for within-herd transmission will result in a slight overestimate of the number of infected farms, because the option that introduction of infection in a herd will not result in transmission is ignored for values of $R_0 > 1$. We do not consider this a limitation of the model given its intended use for preparedness and contingency planning. The results of the stochastic ABM for between-herd transmission are more important to this end. Considering the ABM, we would like to mention two issues of concern. First, the contribution of airborne spread to between-herd transmission is controversial. There is no evidence that airborne spread played a role in FMD outbreaks in Italy (Maragon et al. 1993) or the Netherlands (Bouma et al. 2001). Also, the 2001 epidemic in Great Britain did not provide strong evidence for airborne spread, with the few farms for which airborne spread was considered having a negligible contribution to the epidemic (Hagenaars et al., 2011). The algorithms used for airborne transmission seem to result in an overestimate of this pathway based on the results presented by Bradhurst et al. (2016). However, simulation results with the EuFMDiS demo model indicate a limited contribution of airborne spread to between-herd transmission only. Nevertheless, we recommend to switch off this pathway in the default settings of EuFMDiS. Second, distance-related transmission in EuFMDiS is modelled by the local spread pathway, using a relatively simple algorithm to determine the distance-related probability of infection. Data from FMD outbreaks in the UK and the Netherlands in 2001 have been used to estimate spatial kernel models to account for distance-related spread that are not limited by a user-defined maximum distance (Ferguson et al., 2001; Savill et al., 2006; Boender et al., 2010). Nevertheless, most transmission events initiated by these spatial kernels are in a radius of < 3 km around infected farms. Considering that modelling of the indirect spread pathway in EuFMDiS is analogous to the local spread pathway, but requires a huge effort in quantifying the required input parameters needed,

resulting in high uncertainty for results obtained for the indirect spread pathway, we recommend to merge the local spread pathway and the indirect spread pathway into a single distance-related spread pathway based on a spatial kernel.
A more detailed review of the modelling approach is given in Appendix A.

3.3. Data sources and parameterization

EuFMDiS is a data demanding simulation model which uses many parameters for the different phases of the disease transmission and control processes. The manual clearly explains these different phases going from the within-herd transmission process, the between-herd transmission process with different transmission pathways considered at this level and the disease control process where different strategies can be tested either independently or combined. This structure of the model and its description in the manual facilitates the overall understanding of the model application and purpose by the user. In addition, one of the strengths of the model is that values for all parameters can be provided by the user. However, given the large amount of parameter values required, this quality can easily, and would probably, become a weakness since there is the risk that the user would take the generation and provision of data to the model lightly and compromise therefore the quality of the simulations performed.

Input data into EuFMDiS are organized in a relational database and can be configured for individual countries, regions, holdings and herds. To run EuFMDiS many input parameters need to be parameterized, some of which lack solid data for parameterization. Default values for all input parameters are provided in the pilot version of the model. Disease-related parameters needed for the EBM and on infectivity and susceptibility of different species will differ among virus strains, but not by definition among countries. Hence, the default values of these input parameters need to be carefully chosen and justified by the model development team. Country-specific parameters on herds, contact rates, resources for control, etc. are to be provided by the individual countries. Default values of control-related parameters should preferably be chosen such that they represent the minimal requirements for control as given by EU legislation. These parameters can easily be changed by the user via the graphical user interface (GUI) to explore different control strategies, whereas disease-related and country-specific parameters can only be changed in the database itself.

Detailed data is required on the following components: 1) the livestock population, 2) within-herd and between-herd transmission, 3) disease control and 4) costs due to disease, control and market loss. The data requirement document *EuFMDiS_data_requirements.pdf* explains

the provision of data for items 1, 3, 4, and partly for 2 (covering mainly contact data for the between-herd transmission pathways). These data are important for configuring the model to the specific condition of the member state applying the model. However, data requirements on the parameters regulating the transmission processes are not stressed in this document and are lightly mentioned with some example values provided in the manual. This situation leads to the risk of the user focusing its efforts on the data requested in the *EuFMDiS_data_requirements.pdf* document, which requires substantial work, and take for granted (or fully trust) the default values given in the manual and the example datasets (csv files).

To minimise this risk and facilitate the application of EuFMDiS so that one (paraphrasing the authors) 'enables the model to represent realistically spread and control of FMD outbreaks', it is advised to provide as an appendix a summary of parameter values reviewed from the literature. This could be provided in the form of tables listing estimates for different parameter values (e.g. mean and confidence intervals) and providing the references from where the estimates were taken. Such a table could be provided for, for example (but not limited to), the parameters used for the EBM configuration of the model. We foresee that such tables would reduce the pressure on the user (who has plenty of work collecting herd and movement data) and let the user choose the parameter values or range of values they would like to assess. To further stress the point of providing the recommended tables, it should be also noted that some veterinary services do not have full access to scientific literature. These tables should be updated at least every 5 years as new publications on transmission parameters will come forth.

Considering the instructions for collecting and reporting data to support the modelling of disease transmission and control in EuFMDiS, we concluded that the collection of statistics on direct contacts between farm types regions is straightforward if an adequate identification and registration (I&R) system is employed by the member state. However, the assessment of indirect contacts is much more complicated, especially because the requested parameters are a summary over different types of contacts that might occur with different frequencies, over different distances and with different herd types. The authors state: 'You will need to factor in all the types of indirect contacts and frequencies of these different types of indirect contacts for each source herd type and estimate the likely distribution of contacts with each of the nine possible destination herd types'. We consider this an extremely difficult task and recommend to provide a more detailed worksheet to the member states (e.g. resembling the data used for indirect contacts given in the example for Australia). Although on first sight, it seems as if one would ask more information from the member states, this only helps in making the requested information more explicit. The model development team could then apply

standardized algorithms to summarize the data provided by the member states into the format used by EuFMDiS.

In the Excel templates, the member states are often requested to divide direct or indirect contacts given over, e.g., seasons or herd types. In this, they are asked to provide percentages and to ensure that the totals equal to 100%. This task could easily be simplified by just asking to divide the total number over the different categories. The model development team could then use an algorithm to change the values into probabilities or percentages. Furthermore, it could be helpful to include a true/false statement in the Excel templates to check if the values provided indeed add up to the total number (or 100% as it is now).

3.4. Model outputs

The model provides ample opportunities for the user to explore different outbreak scenarios (e.g. depending on the herd type and location of the first infected farm) and control strategies (including ring culling and vaccination). There is a lot of parameters that can be changed in the GUI, although not all of them are intuitively understood. Other parameters, e.g. on transmission probabilities, can only be changed in the database (csv files) or in the configuration settings (txt files). Unexperienced users are not likely to touch those, although choices made here will also have major impact on model results. The multitude of input parameters that can be changed is considered both a strength and a weakness of EuFMDiS. Although it makes the model very flexible to evaluate different outbreak scenarios and control strategies, it can also hamper a proper use of the model, especially if the end user has no firm epidemiological background. Therefore, explicit instructions for the end user are needed when EuFMDiS is to be used for contingency planning.

The user interface has many options for ‘observing’ an FMD outbreak in EuFMDiS and this is an appealing feature EuFMDiS. Unfortunately, graphical results are not stored after the simulation. The model stores several csv files for subsequent analysis by the user. Headings of the columns in these files are not self-explanatory and need more documentation.

Output of scenarios run with EuFMDiS can be compared, among others, for the number of infected herds, the number of herds culled and/or vaccinated, the length of the epidemic and costs of the epidemic. Furthermore, information is provided on each of the infected herds including the pathway that resulted in infection. As such, results of the tool are useful for preparedness and contingency planning.

Information on delays in control processes due to limited resources cannot easily be derived from the model, whereas we think that such information would be helpful for contingency planning, e.g. by evaluating if available resources are sufficient to control 95% of the outbreaks without major delays. Although the model takes into account the number of teams for each control activity set by the user, the minimum or optimum value required to implement control measures can now only be found by trial and error (if at all). We thus conclude that the usefulness of the model could be improved by a more explicit visualisation of the lack of resources for control measures and additional calculations to define the minimum or optimal number of teams required for the different control measures.

Our main concern in evaluating whether the model produces sensible outputs is the impact of the default input parameter values on the results as discussed above. The parameters set for the EBM will most likely result in an overestimate of the number of infectious animals in an infected herd, resulting in a high infectiousness of those herds. Simulating an FMD outbreak starting in a commercial fattening pig herd in Austria confirmed our concern with most iterations resulting in large epidemics when a stamping out only control strategy was chosen. Even with a 1 km ring culling strategy, these epidemics were unexpectedly large. Observed results for between-herd transmission made, however, biological sense with the majority of secondary infections caused by local spread, especially after detection of the first infected herd. The contribution of airborne spread was relatively small, even with an outbreak starting in commercial pig farms, which we think is much more realistic than results of AADIS as presented by Bradhurst et al. (2016).

4 Conclusions

EuFMDiS is a very detailed simulation model explicitly modelling FMD transmission mechanisms. This contributes to an intuitive understanding of the model by the user. The model uses a hybrid modelling approach combining a deterministic EBM for within-herd transmission and a stochastic ABM for between-herd transmission, resulting in a computationally efficient model. We concluded that transmission pathways for between-herd transmission in EuFMDiS could be simplified by using a spatial kernel to simulate distance-related transmission that covers both local spread and spread by indirect contacts. This would reduce the number of uncertain and non-validated input parameters in the model. The contribution of airborne spread to between-herd transmission in EuFMDiS should be carefully monitored to ensure plausible results. We recommend to switch this pathway off in the default model settings. Built-in control measures in EuFMDiS cover the main control

measures, both compulsory and optional, as given in EU legislation. We recommend to select only the minimal requirements for control in the default settings of the model.

EuFMDiS is a data demanding simulation model that uses many parameters for the different phases of the disease transmission and control processes. Default parameters in EuFMDiS should be carefully chosen and supported by scientific literature when available. This applies especially to disease transmission parameters that are uniform over countries and regions such as the input parameters of the EBM.

EuFMDiS provides ample opportunities for the user to explore different outbreak scenarios and control strategies. To this end, input parameter values/settings can be changed in the graphical user interface (GUI). The GUI has many options for 'observing' an FMD outbreak in EuFMDiS and this is an appealing feature of EuFMDiS. However, output stored in csv files is not sufficiently annotated and lacks the opportunity to optimize resources for control measures. Trained epidemiologists should be available to support the end users of EuFMDiS when deploying the model to evaluate FMD outbreak scenarios and control strategies.

Our main concern about EuFMDiS is the multitude of input parameters that need to be parameterized and for which biological or veterinary observations are partly lacking. As a consequence, input into EuFMDiS relies to a large extent on expert opinion. Apart from this, default values of parameters that can be derived from experimental or field data are not always plausible, especially in the EBM for within-herd transmission. We recommend to reconsider the default values used for the EBM and to provide the user with a summary of parameter values for the EBM reviewed from the literature. A sensitivity analysis to investigate the impact of uncertain model parameters in both the EBM and ABM on model results could help in identifying those parameters for which a good parameterization is essential to obtain robust model results. Such a sensitivity analysis is currently lacking.

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Appendix A:

Detailed review of the user manual

A1 General remarks

- Many abbreviations are used in the manual. These are not always explained in the text when first used. Most abbreviations can be looked up in the glossary at the end of the document, but some are missing in the glossary as well (e.g. ODE, NSW, VIC).
- The tables with parameters, descriptions, locations and example values are not numbered in the document. A column describing the sources/references for values sourced from literature is missing. Also, units for parameters need to be provided when possible. Currently units are provided for some parameters and not for others.
- From the manual, it is not exactly clear which calculations are performed on the herd level and on the holding level. Having read Bradhurst et al., 2015, we assumed that disease transmission is modelled at the herd level and disease control at the holding level.
- The terminology used to distinguish between herds and holdings is not always used correctly. In the manual, the term farm is sometimes used to indicate a holding. Vaccination zones are, e.g., defined on a per herd basis, whereas one would assume that these are calculated on a per holding basis as all control activities are performed on the holding level.

A2 Equation based model for within-herd transmission

Values used for the EBM (as given in the *ebm.csv* file and in Table 3 on page 26 of the manual) are herd type-specific and therewith also species-specific. Default values chosen have mostly been derived from experimental studies and result in an extremely high within-herd transmission of FMD virus with R_0 values ranging from 5.6 for commercial small ruminants to 32 for large-scale commercial breeding and fattening pigs. This, together with the deterministic nature of the EBM, will overestimate both the number of infected herds (no fade out possible if $R_0>1$) and the infectiousness of the herds. Furthermore, values for the EBM might differ among FMDV strains and this is not accounted for in the model. Given that results of the deterministic EBM are the basis for the ABM simulating between-herd transmission, we conclude that the input values for the EBM should be chosen carefully.

Specific issues to consider:

- In Table 3, the parameter 'clinical lag' is used. Although understandable, the correct epidemiological term for this phase is 'incubation period'.
- The transmission parameters in Table 3 are higher than most published transmission parameters. It is advised to update the values of the EBM in both EuFMDiS and the manual to more realistic values. Recent literature is available in which, e.g., the durations of the latent period, incubation period, and infectious period were studied (Yadav et al., 2019). Furthermore, it should be realised that viral doses used to infect animals in experimental settings are often very high compared to what can be expected in the field, in order to have a high probability of infection in individual animals. As a consequence, estimated R_0 values from epidemics are usually lower than those estimated from animal experiments (Dekker and Hagenaars, 2019).
- It is not exactly clear how the value for the proportion clinical in Table 3 (set to 1) should be interpreted. It should be noted that not all FMD-infected animals will show clinical signs (Bouma et al., 2004; Orsel et al., 2005; Orsel et al., 2009).
- Values set for the seropositive response in FMD-infected animals and the duration of natural acquired immunity need to be reconsidered. Natural, strain-specific immunity to FMD is most likely lifelong. Vaccine-induced immunity by emergency vaccines (i.e. high quality vaccines) is much longer than 6 months (Terpstra et al., 1990; Selman et al., 2006; Cox et al., 2010).
- Results of the EBM are not only used to estimate the proportions of susceptible, exposed, infectious and recovered animals, but also the proportion of animals showing clinical signs and the proportion of animals that seroconverted. The SEIR model described in the manual could thus include a clinical and a seropositive compartment. This could also be visualised in Figure 2.
- To what extent are the EBM results on clinical prevalence used to determine reporting and detection probabilities?
- It is advised to provide an overview of possible values for input parameters of the EBM based on a (systematic) literature review so that the user can choose a reasonable estimate for these input parameters. Values from literature could be presented in a table including statistics such as minimum, maximum, mean and median values and/or forest plots, also indicating relevant information on virus strains. References should be provided for all values given.
- Perform a sensitivity analysis to investigate the sensitivity of model results to parameter values used in the EBM.

A3 Agent based model for between-herd transmission

A3.1 Local spread

Many FMD models include a distance-related transmission rate. Usually, the parameters for this transmission rate have been based on observations from historical outbreaks (e.g. Boender et al., 2010 for the FMD epidemic in the Netherlands in 2001 and Ferguson et al., 2001 for the UK epidemic in 2001). In contrast to these spatial kernels for which distance-related probabilities have been estimated from outbreak data, local spread in EuFMDiS is modelled explicitly taking into account various parameters that mimic real-world activities. The equation for local spread includes parameters on infectivity and susceptibility of herds, biosecurity levels, seasonal effects, etc., some of which will be difficult to quantify. In contrast to kernels that model spread over any distance, local spread in EuFMDiS is restricted to a user-defined radius. The default of this radius has been set to 3 km. Enlarging this radius potentially results in a significantly higher number of herds that are at risk to local spread (to give an example: by extending the radius from 3 to 4 km, the surface of the area at risk is almost doubled) and a higher probability of infection for individual herds with the probability of infection (p_i) linearly decreasing over this radius (w_d).

Questions that arise are:

- How is the baseline probability that a local contact between herds results in infection (p_b) set? What data have been used to support the default value of 0.5?
- How are the biosecurity weight (w_b) and the seasonal weight (w_x) defined? What data have been used to support these values? These parameters are not explained in the manual.
- What is exactly meant by the detection weight (w_n)? How is the value for this determined? This parameter is not explained in the manual.
- Although it is stated that infectivity weights of source herds (w_i) are normalized across the herd population, they can have a value > 1 when the population mean is used as the denominator. In theory, this could result in a value of the probability that the local contact results in an infection (p_i) > 1.
- The susceptibility weights of cattle and sheep are not supported by experimental data, in fact the estimates used by Risk Solutions (2005) are extremely far from the experimental estimates by Bravo de Rueda et al. (2014; 2015).
- The impact of the species infectivity power and species susceptibility power (P_i and S_i) are not understood intuitively. How have the default values for these been set? And how sensitive are model results to these values?
- The number of exposed animals in the destination herd (n) is sampled from a Betapert (1,2,5) distribution. How likely is it that > 1 animal is exposed and initiates the within-

herd transmission as modelled by the EBM? Would these values differ among herd types? And would the number of exposed animals in the farm be related to the biosecurity level of the farm? And if so, does the model account for a correlation between the biosecurity weight and the number of exposed animals?

A3.2 Direct spread

The Binomial model is used to estimate the probability that transfer of animals from the source herd results in infection of the destination herd. This assumes a random distribution of infectious animals in the herd, analogous to the assumption of homogeneous mixing in the EBM to model within-herd transmission.

Questions that arise are:

- Does the direct spread pathway also operate in the local spread radius?
- Is the herd type of the destination herd equal to the herd type of the source herd? Information available in the table *transborder_direct_movements_off_premises_type.csv* does not allow for a distinction between herd types/holdings, nor does the template to provide information (*Within country animal movements.xlsx*).
- How are movements between holdings in different member states modelled? The information in the table of Section 3.5.3 does not correspond with the information in Section 3.5.5 and Figure 4.

A3.3 Indirect spread

Modelling of the indirect spread pathway is analogous to the modelling of the local spread pathway. Main difference is that all herds in the local spread radius have a probability of getting infected based on distance to the source farm, while for the indirect spread farms at risk are sampled based on a contact matrix and distance distribution by herd type. We suggest to model local spread and indirect spread together by using a more sophisticated distance-related transmission rate (spatial kernel) that also allows transmission over longer distances (indirect spread), but gives highest probabilities of transmission on short distances (local spread).

Different types of indirect contacts (e.g. veterinarians, artificial insemination technicians, bulk milk tankers, feed delivery vehicles) will have different probabilities of disease transmission. In the current model, all indirect contacts have, however, been assigned the same probability. When parameterizing the model, the user can weigh the different contact types to estimate the overall number of indirect contacts. This is, however, up to the member states (users) of

EuFMDiS rather than the development team. We advise better support for the parameterization of this pathway to the users.

The potential contribution of resources (personnel and equipment) used to control FMD outbreaks to indirect spread of the virus between farms is not considered in EuFMDiS, nor in any other transmission model. It would be interesting to see if it would be possible to include this by considering, e.g., the number of people per team and the number of vehicles used.

A3.4 Airborne spread

The contribution of airborne spread to between-herd transmission of FMD is controversial. Assumptions in EuFMDiS are based on publications by Donaldson et al. (2001), Donaldson and Alexandersen (2002), and Alexandersen et al. (2003) evaluating airborne spread during the UK epidemic of 2001. However, analyses of other epidemics did not find evidence for airborne spread (e.g. Maragon et al., 1994; Bouma et al., 2001). In EuFMDiS, only pig herds are considered capable of transmitting FMD by airborne spread. This seems a valid assumption given the relatively high amount of virus excreted by pigs in aerosols (Donaldson and Alexandersen, 2002). The probability of transmission by airborne spread takes into account the susceptible herd species, herd size and distance from the infected herd. A species-specific probability that a single animal will become infected (P_{sp}) is used. No information is given on values used for this probability and where values have been derived from. Also, no references are provided for other values used to model airborne spread (e.g. plume coefficient A, plume exponent B, exponential decay constant C).

Results of AADIS (Bradhurst et al., 2016) indicate that local spread and airborne spread are the main pathways for between-herd transmission if the seed herd is a pig farm. We recommend to reconsider the contribution of airborne spread to between-herd transmission, taking into account the issues below. Furthermore, we recommend to switch off this pathway in the default settings of EuFMDiS.

Specific issues to consider:

- Considering the formulas for airborne spread, it seems that the number of infectious pigs in the source herd is only used to model the distance of the viral plume. It is, however, not used to estimate the viral concentration in the plume as the model uses a constant probability that a single animal of the susceptible species will become infected (P_{sp}). It would make sense to also model the viral load in the plume as this will depend on the number of infectious pigs in the source herd (and the days post infection for each of the individual pigs). It is unlikely that all infectious pigs in a herd

will exhale the maximum viral concentration as determined in experimental work. Furthermore, only part of the exhaled virus will be emitted from the stable.
NB: When quantifying the amount of virus exhaled by pigs, authors often refer to the paper of Donaldson et al. (1982) that reported the highest maximum excretion found in literature. However, a review of several studies indicated that the average excretion found in experimental studies was on average 1.6 $\log_{10}$ lower (Dekker et al., 1996).

- The formula to calculate the distance of the viral plume (d) now takes the maximum of the calculated distance or the maximum distance (M). It should, however, take the minimum of these two values. Furthermore, the authors should explicitly state which log base is used in the formula. Understanding that the formula was based on data from Donaldson et al. (2001), we concluded that it was $\log_{10}$ rather than ln.
- Calculating the distance of the viral plume for different numbers of infectious pigs at the source farm learns that this plume will only go beyond the local spread area (radius 3 km) if >250 pigs would be infectious. How realistic is it that a farm will not have been detected yet if > 250 pigs are infectious?

A3.5 Spread via assembly centres

Spread via assembly centres seems to be only used to model transmission of FMD between countries, which is reasonable. However, the processes in modelling this pathway are not described in detail and questions arise whether assembly centres are treated only as 'stepping stones' that distribute infected animals, or that disease spread on the assembly centres is involved. Animals transported to assembly centres might stay for a few days and spread the disease to other animals. Furthermore, the transport off assembly centres might result in transmission to > 1 herd. It is recommended to include a statement on inter-member state spread in the EuFMDiS key assumptions.

A3.6 Control measures

Built-in control measures in EuFMDiS cover the main control measures, both compulsory and optional, as given in EU legislation. An overview of the main control measures of EU Directive 2003/85 is given in Appendix B. Default settings in EuFMDiS include a national movement standstill of 3 days and initial protection and surveillance zones of 10 km and 25 km, respectively. We recommend to select only the minimal requirements for control in the default settings of the model.

In this part, algorithms of how exactly calculations are performed are missing. For instance, when it is stated that 'true reports are generated stochastically based on an infected herd's clinical prevalence, the probability of reporting and the expected time to report' (p. 47), one

would like to know how this is exactly incorporated in the model. One of the few formulas provided is the one for the probability of holding detection (Section 3.6.1.2). It is, however, not clear how the values of the parameters a, b and c of this function have been estimated and how this formula relates to e.g. the clinical prevalence within the herd.

A3.7 First IH detection

- The option of a fixed first IH detection is not so realistic. If used, a reasonable estimate for the high risk period should be used.
- Considering the passive first IH detection, the probability of detection is driven by the clinical prevalence of infected herds. It is, however, not clear how the minimum clinical prevalence configured to this end contributes to the probability of detection. It seems as if this is only dependent on the day since infection (formula for y), without taking into account herd type or animal species.
- The probability that a veterinarian suspects FMD and sends samples to the lab is pretty low (0.592), even when assuming that this is a conditional probability given that the farmer reports suspicion of disease. Where is this value based on?
- The confirmation lag used in the default settings is extremely long if one considers that results of a RT-PCR test can be available in 5 hours.

A3.8 Movement restrictions

- A national livestock standstill of 3 days is not required according to EU legislation. It is, however, good to provide the opportunity to implement this measure in the model. However, we recommend to switch it off in the default settings.
- Different radii can be implemented for the protection and surveillance zones in EuFMDiS for the first phase and the second phase of the outbreak. Default radii given for the first protection and surveillance zones (10 and 25 km, respectively) are extremely large and are expected to result in a shortage of resources quickly because of the large number of farms that have to be screened. We recommend to set the radii of both protection and surveillance zones to default values based on EU legislation, i.e. 3 km for the protection zone and 10 km for the surveillance zone (both measured from the infected herd).
- Throttling rates are not only given for the transmission pathways in the different areas of the affected jurisdiction (protection zones, surveillances zones, and free zones), but also for the jump spread pathway. Although explained in the paper of Bradhurst et al. (2016) as an alternative to model between-herd transmission if insufficient data are available to parameterize all transmission pathways, this pathway is not explained in the EuFMDiS manual.

- Many throttling rates have to be estimated by the member states when parameterizing EuFMDiS for their country. Is any guidance provided in how to estimate those rates?
- It seems correct that throttling rates for indirect spread are relatively low. The throttling rate for the protection zones is, however, set at 85%, which we think is too high considering that at the one hand a decrease of indirect contacts is to be expected, but that at the other hand movements of people between farms due to tracing and screening activities will increase.
- Why is no throttling rate applied to local spread, considering that local spread includes indirect contacts in a radius of 3 km around the infected herd?
- Why are throttling rates also applied to non-infected jurisdictions (NIJ)? One would expect that the livestock standstill will not impact other countries, except for the fact that no imports will occur from the infected country (i.e. a throttling rate for assembly centres is justified).

A3.9 Surveillance

- Only contact holdings, suspect holdings, traced holdings, and holdings in the protection zones are visited for surveillance. This is in accordance with EU legislation.
- It is recommended to define the local PZH radius equal to the PZ radius used by the model and as defined in the movement restrictions table in the database, rather than setting this value separately in the disease config file.
- It is not clear how the parameter 'maximum days undetected' (default value set to 10 days) is used in the model calculations. The assumption that the surveillance team will for sure detect infection at the farm after 10 days, independent of the clinical prevalence and the farmer's observations, does not take into account the potential occurrence of subclinical infections in, e.g., sheep flocks (Dekker et al., 2005).
- The component of surveillance that contributes most to the detection of infected farms is passive surveillance. Is there any way in which increased awareness of farmers has been modelled in EuFMDiS to result in earlier detection of farms by passive surveillance after detection of the first infected holding?

A3.10 Tracing

- A backward tracing window of 14 days is short. Retrospective studies into, e.g., the 2001 FMD outbreak in the Netherlands, indicate that this period should probably be longer (Bouma et al., 2002). The authors of the model acknowledge this by setting the time period till detection of the first infected holding to 21 days when the option of a fixed first IH detection is chosen.

A3.11 SH Reporting

- The ratio of false suspect holdings to true suspect holdings is based on McLaws et al. (2007). However, based on 6182 suspected premises and of which 2026 turned out to be FMD cases, we arrived at a ratio of 2.05.

A3.12 IH Operations

- Quite some states are given for infected holdings: cull pending, cull in progress, disposal pending, disposal in progress, decontamination pending, decontamination in progress, resolved. What is the time step with which holdings can proceed to the next state? It seems that all transmission in EuFMDiS is modelled on a daily basis. If IH operations would also be modelled using steps of one day, the IH operations will at least take 6 days and in most cases many more days based on the values provided in the herd type table of the database. This seems far too long. Furthermore, at which state is the infectiousness of the herd removed? When disposal is pending, but cull is finished?
- It is to be expected that there might also be a shortage of resources for culling, disposal and disinfections. How are priorities set in case of limited resources?
- The default value set for the ring culling radius is too wide. In the Netherlands, a radius of 1-2 km is applied, but only for high risk areas (i.e. densely populated livestock areas).

A3.13 Vaccination

Many options are offered to mimic vaccination strategies to control an FMD epidemic. These seem to provide sufficient possibilities to explore alternative vaccination strategies with the model. The terminology used for the different vaccination strategies should, however, be more precisely defined. Suppressive, protective and mass vaccination are not very precise terms and are used next to ‘waste’, ‘salvage’, and ‘retain’. It is recommended to use terms as ‘vaccination to kill’, ‘vaccination to live’ and ‘prophylactic vaccination’ and to use the same terminology across the text and tables.

Questions that arise are:

- Is it realistic to assume that vaccination will result in a 100% herd immunity (Fig. 6)? In the table of Section 3.6.7, values are given for vaccine effectiveness, suggesting that EuFMDiS takes into account indeed that not all animals will be immune to FMD after vaccination.
- FMD virus vaccine effectiveness is not known for vaccines. But potency is normally measured. The relation between potency (PD_{50}/dose and) % protection has been established, e.g., a 3 PD_{50}/dose vaccine protects 70 – 75% of the cattle against a

virulent challenge in the tongue (Jamal et al., 2008). However, when 100% of the population is vaccinated full protection against transmission is achieved even when heterologous virus from the same serotype is used for infection (Eblé, 2006; Orsel, 2007; Bravo de Rueda, 2015). We therefore question how the vaccine effectiveness parameter is used in the model calculations and if it is relevant to use these parameters at all (assuming that 100% of the animals in a herd will be vaccinated).

- EuFMDiS has an option to enable a shared vaccine bank rather than using national vaccine banks. In the EU there is a shared vaccine bank and only few countries have, in addition to the shared vaccine bank, their own national vaccine bank. How is this reflected in the model?
- The authors provide a parameter for the vaccine dose per species. The only FMD vaccine that received a central European registration is Aftovaxpur DOE. This vaccine has a 2 ml dose for all species (Aftovaxpur DOE received a marketing authorisation valid throughout the EU on 15 July 2013. More information available at: https://www.ema.europa.eu/en/documents/product-information/aftovaxpur-doe-epar-product-information_en.pdf)
- The detection density trigger parameter is not clearly described in the manual.
- The abbreviations NSW and VIC are not explained in the manual.

A3.14 Team resources

- The vaccination resources ramp start day should equal the vaccination program start day or could be a day later in the future. Are these two parameters linked in the model to avoid unrealistic scenarios?
- Is it expected that post-outbreak surveillance resources can be available at the maximum level from the moment they are needed, as these resources are not increased over time in the model?
- The resources needed for the post-outbreak surveillance will strongly depend on the vaccination strategy used (number of herds vaccinated; vaccination to waste or to retain).

A3.15 Post-outbreak management

The authors indicate that the development of this module had lower priority. The design of the post-outbreak surveillance is especially important when a vaccination to retain strategy has been used, as each suspect case will delay the moment at which the FMD-free status is regained. The authors also mention the probability of false positive test result due to imperfect test specificity. This is an important issue indeed in the final screening as most, if

not all, positive test results are expected to be false positives. It is, however, not clear how false positive test results are dealt with in EuFMDiS.

- In EuFMDiS, the number of herds that need to be sampled in a given cluster, and the number of animals within a herd that need to be sampled, are calculated using formulas from Cannon and Roe (1982). The level of 5% set for the target prevalence at herd level is disputable. According to EU legislation, all holdings in the protection zone should be sampled. In the surveillance zone, a random sample of holdings should be sampled to detect at least 2% of infected herds with 95% confidence. The design prevalence for the within-herd prevalence of sampled holdings should indeed be set to 5% according to EU legislation (EU Directive 2003/85, Annex III).
- EU legislation prescribes the sampling of all vaccinated animals (EU Directive 2003/83, Article 56).
- Vaccinated herds do not need to be tested if a vaccination to remove (waste or salvage) strategy was used. Does the removal rate in the species table of the database indicate how quickly vaccinated herds can be culled and disposed of? Why not use the available resources as set in paragraph 3.6.8?
- The formula used for the probability of a false positive test result is only valid at the herd level if the herd is free of disease (i.e. prevalence=0).
- The laboratory test for screening in non-vaccinated herds could be the same as the NS ELISA used in vaccinated herds. But the confirmatory test in non-vaccinated herds is probably the VNT and will not be the same as the tests used in vaccinated herds. The C-ELISA is not widely used, so naming it as an example in the table of Section 3.6.9 is not correct.
- The value of the trigger day in the Table of Section 3.6.9 is set to 30. EU legislation prescribes that sampling should not start before 21 days since the elimination of the animals on the last infected holding (EU Directive 2003/85, Annex III).

A3.16 Outbreak costing

Costs are calculated at three different aggregation levels: the animal level (e.g. culling, disposal, vaccination); the herd level (e.g. surveillance, disinfection); and the country level (e.g. daily costs for control centres, daily trade losses). This is reasonable, although some costs are difficult to estimate at either the animal or the herd level. Vaccination, e.g., will incur a cost per animal for handling the animal and the vaccine, but also a cost per herd for sending a vaccination team to the herd. Not much detail is provided on how costs have been determined for the various categories. The costs as specified in the *herd_type.csv* file are very precise but do not seem to vary over jurisdictions. Loss of trade costs definitely have to be

estimated for each jurisdiction separately, as these largely depend on the amount of animals and animal products exported by the jurisdiction. Furthermore, it should be considered that an epidemic will not by definition result in an export ban for the whole country. Although the costs give an impression of the costs of an FMD outbreak under different control strategies, comparisons could also be made based on number of infected premises, number of premises and animals culled, and length of the epidemic. The latter option is preferred if reliable cost estimations cannot be made.

A3.17 Model outcomes

The key model outcome parameters are summarised in the EuFMDiS manual and can be retrieved from the csv files that are stored when running EuFMDiS. In the manual, quite some emphasis is given to economic output parameters, whereas we think that comparisons between scenarios and strategies could also be based on epidemiological parameters such as number of herds infected (Num IHs); number of herds culled (which can only be guessed from the number of ring culled holdings (Num RCHs) and the outbreak size (Num IHs) in EuFMDiS); number of herds vaccinated (Num VHs); duration of the epidemic (in EuFMDiS given as the last day of control); spatial area of the epidemic (cum convex hull in km^2). Not all of these parameters are given in the table of Section 5.

A question that arises is:

- What is the difference between member states involved in the outbreak (controlled states) and member states impacted by the outbreak (impacted states)?

Appendix B:

Overview of main EU control measures

EU Directive 2003/85 (Chapter II)

- Section 1 Notification (Legislation should make FMD notifiable, and MS should report outbreaks to EU)
- Section 2 obligatory control measures in case of suspicion
    - Investigation of FMDV status (Human resources)
    - Official surveillance and on-farm standstill (Human resources)
    - Laboratory investigation (Human resources)
    - Only lift control measures if FMD has been ruled out
- Section 2 possible additional control measures in case of suspicion
    - Extend measures to contact herds (Human resources)
    - Temporary control zone (must apply surveillance)
    - Standstill in a larger area
    - Preventive eradication (sufficient epidemiological investigation is obligatory)
- Section 3 obligatory control measures in case of confirmation
    - Investigation of FMDV status (Human resources)
    - Official surveillance and on-farm standstill (Human resources)
    - Laboratory investigation (Human resources)
    - Only lift control measures if FMD has been ruled out
    - Kill all FMDV susceptible animals in the holding (Human resources)
    - Epidemiological investigation
    - Rendering (or other method) of carcasses (Human resources)
    - Disinfection and cleaning (and pest control)
    - Tracing of contacts (also of animal products, like semen, ova and embryo's)
- Section 3 possible control measures in case of confirmation
    - Killing non-susceptible species on a farm (animals that cannot be isolated)
    - Preventive eradication (sufficient epidemiological investigation is obligatory)
    - Emergency vaccination
- Section 4 measures to be applied in special cases
    - Zoo animals (or similar)
    - Border inspection posts/Slaughterhouses/Transport vehicles
- Section 5 Holdings consisting of difference epidemiological units
    - A separate epidemiological unit can be exempted from obligatory control measures
- Section 5 Contact holdings
    - Traced contacts should be considered suspected until proven otherwise
- Section 6 A ≥3 km protection zone should be established
    - Registration of holdings

    - Periodic veterinary inspection
    - Standstill of movement of FMDV susceptible animals (including semen, ova and embryo's)
    - Milk, semen ova and embryos, hides, skins, wool, ruminant hair, pig bristles, meat, meat-products and other animal products shall not be put on the market (unless treated)
    - Transport of manure, feed, forage, hay and straw is prohibited.
- Section 6 A ≥10 km surveillance zone should be established outside the protection zone
    - Registration of holdings
    - Standstill of movement of FMDV susceptible animals (including semen, ova and embryo's)
    - Milk, meat, meat-products and other animal products shall not be put on the market (unless treated)
    - Transport of manure, feed, forage, hay and straw is prohibited.
- Section 7 Regionalisation, movement control and identification
- Section 8 Vaccination
    - Vaccination to live or vaccination to kill
    - 10 km surveillance zone around vaccination zone
- Section 9 Recovery of the FMDV free status

EU Directive 2003/85 (Chapter III)

- Section 10 Laboratories handling FMDV
- Section 11 Diagnosis of FMD
- Section 12 Contingency plans and simulation exercises
- Section 13 Control centres and expert groups
- Section 14 Antigen and vaccine banks
- Section 15 FMD in other species

Clarifications by the developers of the review

The developers thank the review team for their detailed and helpful review. In response to specific recommendations and suggestions, we provide the following comments.

1.Conceptual approach

EuFMDiS covers all control measures that are stated in the EU directives on Foot and Mouth disease control, both compulsory and optional, allowing the user to investigate the impact of all options. A baseline of control measures will be included in EuFMDiS as default settings providing a reference for comparison. The baseline setting will consist of only the compulsory control measures as stated in the EU directives. The compulsory and optional control measures, as applicable in the EU will be annexed to the User Manual.
The input parameters for the equation-based model were selected from available literature at the time that the original AADIS model was developed. The parameters will be revised and clearly documented, including new estimations that recently have become available in literature.

2.Modelling approach

EuFMDiS provides a detailed model structure of between-herd transmission routes using a large number of parameters. For every model there is a trade-off between parameter and model structure uncertainty. Complex models can provide detailed predictions and helpful insights if the data for all the parameters it uses are accurate. Simpler models tend to use fewer parameters for which more accurate data are available but will produce less detailed outputs. EuFMDiS provides the option of using a simpler approach using jump-diffusion spread instead of the individual pathways when reliable data for parameterization is not available. The role of longer distance airborne transmission of FMD remains unclear. While EuFMDiS includes an airborne spread pathway, the user can turn off the airborne spread pathway or constrain it to a shorter maximum distance (currently set to 20 km) if considered to be less important.
Merging the local spread pathway and the indirect spread pathway into a single distance-related spread pathway based on a spatial kernel will be investigated as a user-selectable option. There may be an issue of parameterising this pathway, using the kernel approach over larger distances.

3.Data sources and parametrization

A lot of attention is given to collecting good quality data from the countries to parameterize EuFMDiS. Data collection templates with guidelines have been developed and will be further improved and simplified, where possible. Expert elicitation procedures will be developed to ensure a more standardized approach to collecting these data, where necessary. The EuFMDiS User manual will be revised and updated to provide more details on the default values of the input parameters, including the parameter values obtained from literature review.

4.Model outputs

The multitude of input parameters that can be changed and output variables that are provided is a strength of EuFMDiS. The EuFMDiS user indeed must have sufficient knowledge of veterinary epidemiology and experience with animal disease control to understand the context of the model to use it appropriately. Training in the use of the model is currently an essential component of deploying the model to countries. Considerable effort is being put into training and user support and will develop towards a certification system on 'Good Modelling Practices' for the users.

The model stores several csv files for subsequent analysis by the user. Improvements to the structure, content and documentation of output files has been identified and is planned.

It is difficult, if not impossible, to externally validate the outputs of simulation models for predicting emerging disease outbreaks. The validation will rely more on assessing the quality of the input parameters and the plausibility of the key assumptions of the model. The input parameters, including the local spread probability have been revised after the external review with the aim to increase the quality of the outputs. The plausibility of the outputs is also tested by comparing the results of the same scenarios between the different countries that are currently included in the user group.

The review recommended storage of the graphical results of simulations. This is already available but is disabled by default (via the scenario configuration file). This will be better documented.

5.Improvements to the User Manual

- Disease transmission is modelled at the herd level and disease control at the holding level. This will be clarified in the User Manual
- The use of the terms 'herd, 'farm', and 'holding' will be clarified.
- In Table 3, the term 'clinical lag' will be changed to 'incubation period'
- Possible values for input parameters of the EBM based on literature review will be listed as distributions with values such as minimum, maximum, mean and median values. References will be included.
- The input parameters will be listed in an annex, with their default values and references to the information source that is used.

- Biosecurity weighting is the relative reduction in probability of transmission due to application of biosecurity measures. EuFMD is funding a project to collect data and when these are available the biosecurity weighting will be better documented in the manual.
- The impact of the species infectivity power and susceptibility power (P_i and S_i) will be better documented.
- The probabilities of disease transmission for the different types of indirect contacts can be weighted by the users. This will be better documented, explaining the risk weightings applied to different types of contacts.
- Based on information supplied by participating countries, assembly centers are considered to be used for consignments to single destinations and have high levels of biosecurity. This will be better documented
- The jump and diffusion spread pathways will be better documented in the Manual
- Figure 6 will be modified to show more realistic levels of maximum herd immunity
- There are two options for specifying the vaccine resources (1) each country specifies its own vaccine resource (2) a European shared pool of vaccine that an infected country would have access. These will be documented in the Manual.
- The vaccine dose per species will be specified based on EU registered vaccines as specified by EMA: https://www.ema.europa.eu/en/documents/product-information/aftovaxpur-doe-epar-product-information_en.pdf
- The Post-outbreak management component was not fully implemented at the time of the review. It will be further developed, accounting for the regulations and procedures that are in place in the EU
- Concerning terminology: Member states involved in the outbreak ('controlled' states) actually have infected holdings. Member states impacted by the outbreak ('impacted' states) are not infected but have to deal with operational aspects like surveillance/tracing due to livestock movements. This will be documented in the Manual.
- The description of the EBM will be updated to include details on the derivation of clinical prevalence and seroprevalence.