Manual 1

Risk analysis for Foot and Mouth Disease

WORLD ORGANISATION FOR ANIMAL HEALTH
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World Organisation for Animal Health
12, rue de Prony
75017 Paris, France
Tel.: 33-(0)1 44 15 18 88
Fax: 33-(0)1 42 67 09 87

www.oie.int

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Contents

Background

This Manual provides a general overview of risk analysis and is intended as a guide for the reader who wishes to understand the basics of risk analysis and/or as an introduction for those intending to conduct risk analyses in their country. While much of the material is based on import risk analysis, the manual focuses on the use of risk analysis applied to animal movements both into, and within, countries in South-East Asia and China. The process of risk analysis is outlined, together with some specific examples and possible applications in the South-East Asia/China context.

While this manual is intended only to provide an introduction to risk analysis, examples of actual risk analyses and other, more detailed, guides to risk analysis are included in the reference list at the end of this chapter. In order to ensure that information in this manual is freely accessible, almost all of the references listed are available as open-access documents on the internet. The relevant links are provided in the reference list.

What is risk analysis?

Risk analysis is a process by which we estimate the likelihood of some adverse event occurring, and the consequences associated with that event including hazard identification, risk assessment, risk management and risk communication. In the context of animal health, risk analysis can be described as a structured process for analysing the disease risks associated with movements, both across international borders and domestically, of living organisms and their products (Arthur, *et al.*, 2004; OIE *Terrestrial Animal Health Code* (OIE 2017).

We all use risk analysis in our everyday lives when making decisions such as: whether to cross a road, whether to eat certain foods or whether to take particular modes of transport. The process has been used extensively in economics and increasingly in veterinary and public health. The World Organisation for Animal Health (OIE) has developed international standards for import risk analysis, resulting in dedicated chapters in the OIE *Aquatic and Terrestrial Animal Health Codes* (OIE 2016 a&b)

Animal health risk analyses are often applied to disease risks associated with importing certain species of livestock or livestock products. This process is known specifically as import risk analysis, and is explained in detail in an OIE handbook on import risk analysis (Murray, *et al.*, 2010) but risk analyses can also be applied to processes other than trade, as will be described in the course of this chapter.

In simple terms, risk analysis seeks to answer the following questions (Arthurs, *et al.*, 2004). This list of questions also includes the relevant steps in the risk analysis process:

- What can go wrong? (hazard identification)
- How is it likely to go wrong? (risk assessment: release assessment and exposure assessment)
- What would be the consequences of its going wrong? (Risk assessment: Consequence assessment and Risk estimation; Risk management: Risk evaluation)
- What can be done to reduce either the likelihood or the consequences of its going wrong? (Risk management: Option evaluation, Implementation, Monitoring and review).

How can risk analysis be used by SEACFMD Member Countries?

Livestock movement is a major cause of the spread for FMD in South-East Asia and China, with high volumes of livestock moved over long distances both within countries and between countries in the region (see Manual 5). In order to reduce the risk of FMD spreading through livestock movement, targeted control measures may be implemented at critical points (points identified as high risk in terms of disease spread) along the movement pathways (see Manual 3). Risk analysis is a tool which may be used to: identify the possible pathways along which FMD might be transmitted within, or between, countries (risk pathways); to identify specific points in the pathway where there is increased risk for FMD transmission (critical points) and to identify measures to mitigate the risk of FMD spread through these pathways.

The process of risk analysis can be applied to several different situations for the prevention and control of FMD in South-East Asia and China. Some of these are listed below, but the list is not exhaustive and readers may find other situations where risk analysis can be usefully applied:

- Making decisions on importation of livestock and livestock products (import risk analysis)
- Estimation of the risk of FMD infected animals entering a critical point in a movement pathway (such as a livestock market), and the consequences of that entry.

– To prioritise targets for control measures so that optimum benefit can be gained from limited resources.
– To identify strengths and weaknesses in an existing control system (i.e. assessing the success of domestic movement controls or cross-border controls).

Who should conduct a risk analysis?

According to OIE guidelines, a risk analysis requires a number of different skills and therefore a team approach is often the most effective. However, when dealing with animal diseases, such as FMD, the veterinary epidemiologist will be a vital member of the team given their knowledge of the patterns of disease (Murray, *et al.*, 2010).

How to conduct a risk analysis

Before commencing a risk analysis, it is important to clearly outline the question that you want the risk analysis to answer (define the scope of the risk analysis). This question should define what will be included in the risk analysis. For example:

– What is the risk of FMD virus being introduced to Photong Market in Thailand, and what would be the consequences of this?
– What is the risk that FMD virus is introduced to China through importation of live cattle from Lao PDR?

Once the question has been defined, the risk analysis process can commence. According to the OIE Codes (OIE 2016 a&b), risk analysis involves several key steps. These include:

1. Hazard identification
2. Risk assessment
3. Risk management
4. Risk communication

Figure 1 provides an illustration of the structure of the OIE risk analysis process, including details of some of the processes involved within each of these major categories. Although this has been developed for the purpose of conducting import risk analyses, the same general principles can be applied to any animal health risk analysis process. When conducting a risk analysis, the process of hazard identification, risk assessment and risk management are carried out sequentially whereas risk communication should occur throughout the process.

The steps outlined in Figure 1 are each described in this chapter. However, readers should refer to documents outlined in the reference list for more detailed information and to see application of risk analysis and risk assessment to different situations.

Hazard identification

This is the process of identifying the pathogenic agents of interest. For the purposes of this manual, the hazard is foot and mouth disease virus (FMDV). As part of the hazard assessment, certain features of the virus in the area where the risk analysis is targeted should be considered, such as:

– Existence of suitable hosts for the virus
– Persistence/survival of the virus in the environment (specifically under South-East Asia/China conditions)
– Possible means of viral spread in the area of interest
– Existence of the virus in the areas concerned (prevalence/incidence data)

Risk assessment

The following description is adapted from the OIE handbook on import risk analysis for animals and animal products (Murray, *et al.*, 2010):

Figure 1: The structure of the OIE risk analysis process (Murray, *et al.*, 2010)

Risk assessment is the process of estimating the likelihood and biological and economic consequences of entry, establishment or spread of FMDV within an importing country, but it may also be applied to a zone, province, village, individual livestock holding or even a known movement pathway. The risk assessment consists of four different steps:

i) **Entry assessment**: this step consists of determining the likelihood of an imported (or moved) commodity being infected or contaminated with FMDV and describing the biological pathway(s) necessary for FMDV to be introduced into a particular environment.

ii) **Exposure assessment**: this step consists of describing the biological pathway(s) necessary for exposure of animals and humans in the importing country (or area) to FMDV and estimating the likelihood of those exposure(s) occurring.

iii) **Consequence assessment**: this step consists of describing the relationship between exposures to FMDV, the consequences of those exposures and their likelihood.

iv) **Risk estimation**: this step consists of integrating the results from the release assessment, exposure assessment, and consequence assessment to produce summary measures of the risks associated with the identified hazards.

Risk assessments can be qualitative or quantitative. Which type of risk assessment is used will depend on a number of factors, including: the purpose of the risk assessment (i.e. is quantitative risk assessment necessary?) or the data available (i.e. is quantitative risk assessment possible?).

- **Qualitative risk assessment:** Where the output of a risk assessment, such as the likelihood of an event occurring or the magnitude of the consequences, are expressed using descriptive terms such as high, medium, low or negligible.
- **Quantitative risk assessment:** An assessment where the outputs of the risk assessments are expressed numerically.

A qualitative risk assessment is suitable for the majority of risk assessments, and is the most common type undertaken for routine decision making. In some situations, it may be useful to adopt a quantitative approach to support the qualitative assessment and gain further insights, identify critical steps, assess the impact of uncertainty in more details, or compare risk-mitigation strategies. However, quantification is not necessarily more objective or precise than a qualitative approach (Murray, et al., 2010). The reference list includes examples of quantitative and qualitative risk assessments, and the reader is encouraged to examine how each method is applied in practice.

A qualitative risk analysis will use descriptive categories to assign a level of risk to different events within risk pathways. An example of the types of terms used are provided in Table 1

Table 1: Suggested risk categories for qualitative risk analysis (Weiland, et al., 2015)

Risk category	Description
Negligible	The event is so rare that it does not merit to be considered
Very low	The event is rare but cannot be excluded
Low	The event is rare but does occur
Medium	The event occurs regularly
High	The event occurs very often
Very high	The event occurs almost certainly

Quantitative assessments will usually use measures of probability to describe the likelihood of an event occurring, sometimes these will involve point estimates where a single probability figure is assigned to each of the steps in a risk pathway, or sometimes probability distributions are used. A detailed description of using probability distributions in risk assessments is beyond the scope of this manual, but the reader is directed to the following references (some of which are examples of quantitative risk modelling conducted in South-East Asia and China) for more information in this area: Wongsathapornchai, *et al.*, 2008; Smith, 2012; Vose, 1997. There are software packages available which can be used for quantitative risk analysis using probability distributions. One such program is an open-access add-in to Microsoft Excel, developed by Dr Greg Hood (Hood, 2010) and can be accessed via the following link: http://www.poptools.org.

Entry assessment

This is the key step for assessing the likelihood of FMDV entering a country/zone through movement of live animals, animal products or fomites. In order to assess the likelihood of this introduction, all the possible pathways by which entry might occur (and all the steps within those pathways) need to be identified. These 'risk pathways' form a key component of the risk assessment process. These can be shown as pathways of events which need to take place in order for FMDV to enter the area of interest, or they can be presented as scenario trees, the same information is presented below in two different ways:

Risk pathways

The risk pathways illustrate all the possible routes by which FMDV might be introduced to an area (in this example, a livestock market) including consideration of all possible risk materials on which FMDV might be transmitted. The risk pathways will also include information on current control measures. In the example shown in Figure 2, the pathway for introduction of FMDV via live animals entering the market shows that only infected animals not showing clinical signs would be permitted to enter the market. Therefore, this suggests that there is physical examination of animals entering the market and only those without clinical signs will enter. The layout (but not the content) of the risk pathway in Figure 2 is based on a risk assessment conducted by Weiland, *et al*., (2015).

Scenario trees

Scenario trees are another way of illustrating the routes and events that may lead to FMDV being introduced to an area. The scenario tree presents the information as a pathway of expected events and all the failures which could occur, culminating in the occurrence of the identified hazard (Miller, *et al*., 1993), i.e. introduction of FMDV into a market. At each step in the scenario tree, the likelihood that the event will occur is estimated. This may involve assigning a risk category such as high, medium, low (qualitative risk assessment) or a probability (quantitative risk assessment). Based on the combined likelihood of each step occurring within the pathway, an overall risk level is assigned (or calculated if quantitative assessment is used) for the whole pathway.

The following examples are scenario trees for introduction of FMDV into a market by movement of live animals (Figure 3) and movement of vehicles (Figure 4).

Once the risk pathways and scenario trees have been developed, data will be needed in order to estimate the risk of FMDV entry via the different pathways. Even where qualitative risk assessments are conducted, data will still be needed in order to make informed judgements on

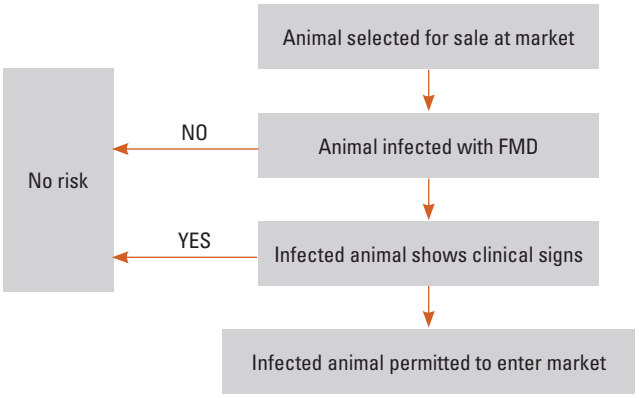

Figure 3: A scenario tree showing the necessary steps for introduction of FMDV to a market in Thailand through entry of live animals

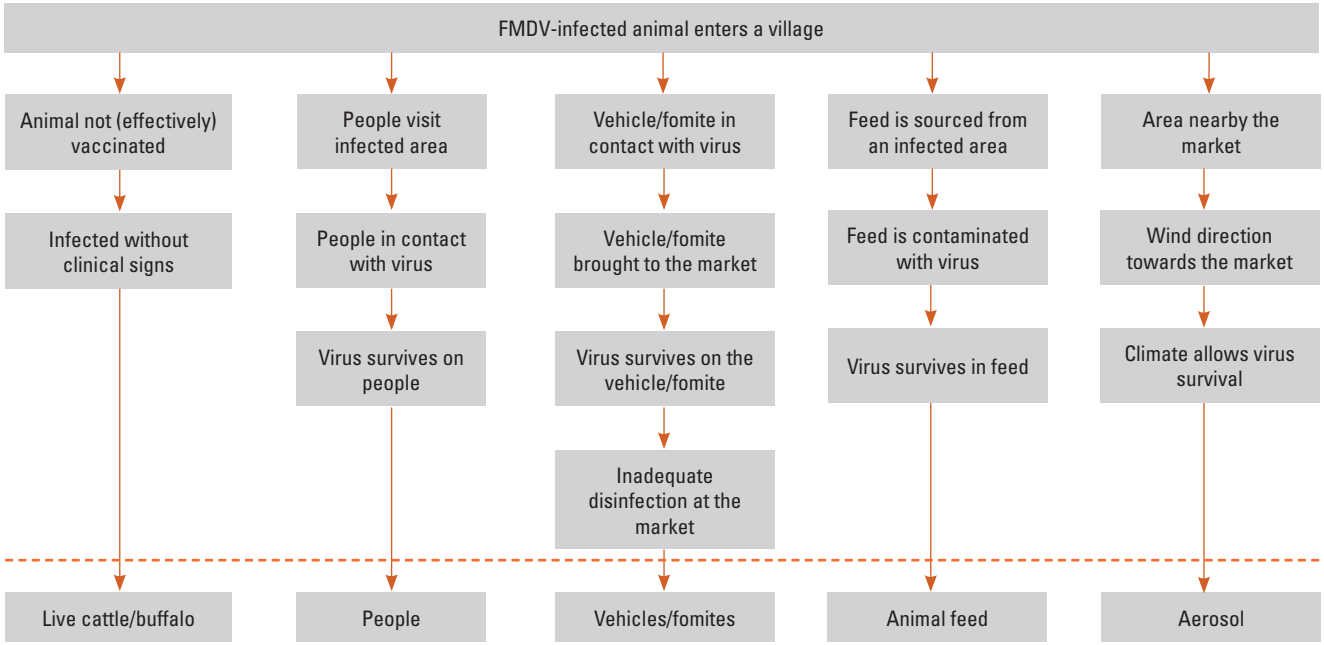

Figure 2: FMD entry risk pathways for a livestock market in Thailand

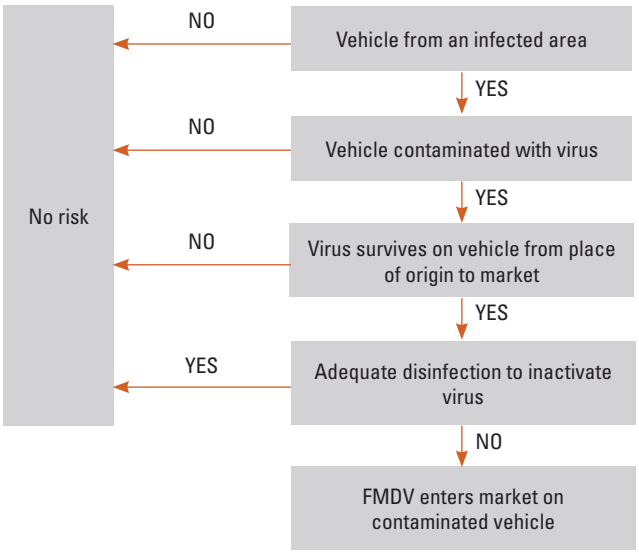

Figure 4: A scenario tree showing the necessary steps for introduction of FMDV to a market in Thailand through entry of vehicles.

the risk of each step. The types of data which might be used is described in more detail in a later section of this chapter. Readers are encouraged to examine published risk assessments (see the reference list) for more information on the use, and limitations, of different sources of data.

The risk assessment may be concluded at this point if there is a negligible likelihood of the commodity being infected or contaminated with the hazard when imported. (OIE Handbook on IRA, 2004) or If the entry assessment demonstrates no significant risk, the risk assessment does not need to continue (OIE *Terrestrial Code* Article 2.1.4.).

Exposure assessment

The following definition is adapted from Murray, *et al.* (2010):

An exposure assessment is the process of describing the biological pathway(s) necessary for exposure of susceptible animals in the importing country (or other area) to FMDV released from a given risk source, and estimating the probability of the exposure(s) occurring, either qualitatively or quantitatively.

The risk assessment may be concluded at this point if the likelihood of exposure is negligible. (OIE Handbook on IRA, 2004) or If the exposure assessment demonstrates no significant risk, the risk assessment may conclude at this step (OIE *Terrestrial Code Article* 2.1.4.).

In the same way that scenario trees are developed for release assessments, they are also used for exposure assessments in order to show the pathways necessary for susceptible animals to be exposed to FMDV following its introduction into an area.

Again, each step in the scenario tree can be assigned a likelihood category (qualitative assessments) or probability (quantitative assessments) in order to determine the overall risk of exposure via a specific pathway.

In order to explore the risk of exposure to FMDV, the different exposure pathways should be considered. For example, if an FMDV infected animal enters a village, the possible routes by which the local livestock population might be infected are as follows:

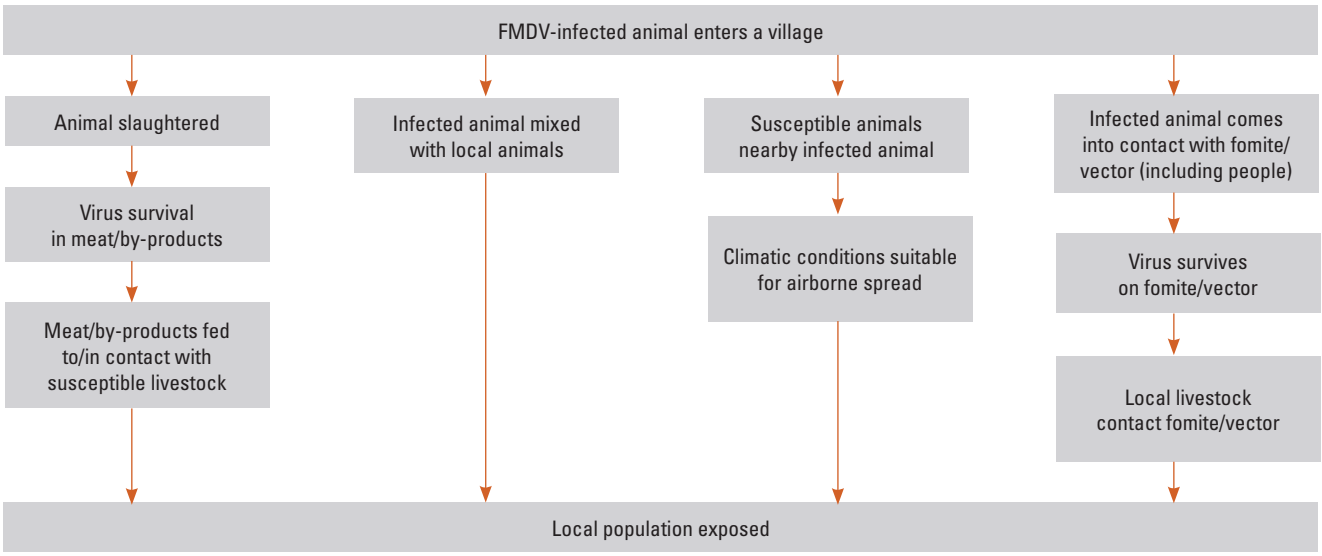

Figure 2: FMD entry risk pathways for a livestock market in Thailand

1. Direct contact between the infected animal and local susceptible livestock
2. Meat from the infected animal fed to/contacts local susceptible livestock
3. Aerosol transmission between the infected animal and local susceptible livestock
4. Contamination of fomites (vehicles, equipment, footwear, etc.) or vectors (eg humans) with virus from the infected animal and then contact with that fomite/vector by other susceptible animals

In order to assign levels of risk to these different pathways, it is important to have a detailed understanding of factors in the area concerned such as: livestock density, control measures (including biosecurity measures), husbandry practices, cultural practices, climate, virus survival, etc. which will affect the likelihood of exposure through these different routes. More detailed information can be put into each of these routes (exposure pathways) in order to identify the events necessary to lead to exposure by each of the routes.

The following example shows some simple exposure pathways for an FMDV infected animal entering a village, assuming that there are no biosecurity protocols operating when bringing livestock into the village.

Each of the pathways may then be assigned a level of risk based on local conditions, livestock density, practices, etc.

A summary of an exposure assessment (for a qualitative exposure assessment) based on the pathways in Figure 5, is shown in table 2. Note, this is just an example and the same pathways may be assigned different levels of risk depending on the local situation:

Consequence assessment

A consequence assessment describes the consequences of a given exposure to a hazard (FMDV), and estimates the probability of them occurring. The first consequence of interest is active infection of at least one animal (Murray, *et al.*, 2010).

Will every exposure lead to infection?

It should be noted that infection of an animal with the pathogen in question (FMDV) is counted as part of the consequence assessment, rather than the exposure assessment. The reason for this is that exposure to virus will not, in every case, lead to infection. FMD is a highly contagious disease and so contact between an infected animal and a susceptible animal will usually lead to infection. However, exposure of susceptible animals to contaminated fomites will only result in infection if there is sufficient virus present on the fomite to cause infection, i.e. whether exposure leads to infection is a dose-dependent event. When conducting a risk analysis involving a highly contagious disease such as FMD, it might be assumed that every exposure leads to infection. However, if this assumption is made it should be clearly described in the risk analysis report.

The risk analysis may be concluded at this point if either no consequences are identified or the likelihood for each of the consequences identified is negligible.

When conducting a consequences assessment for exposure to a particular hazard (in this case, FMDV), you should provide a reasoned, logical and referenced discussion to the following (taken from Murray, *et al.*, 2010):

- Estimate the likelihood that at least one animal becomes infected
- Identify the biological, environmental and economic consequences associated with the entry, establishment or spread of FMDV, and their likely magnitude
- Estimate the likelihood of the occurrence of these consequences

Table 2: A simple exposure assessment for an FMD infected animal (cattle) entering a village where there are no biosecurity measures in place

Exposure pathway	Likelihood	Explanation
Meat	Medium	Although most muscle meat is allowed to go through rigor mortis changes which should destroy FMD virus, virus may survive in bone marrow and lymph nodes, and some local people feed waste meat products to pigs
Direct contact between infected animal and local susceptible animals	Very high	In this village, farmers and traders will generally bring all purchased animals back to their property where they will be able to contact other FMD susceptible animals. There is no quarantine protocol for this village
Fomites/Vectors	Medium	Given that there is a low level of biosecurity in this village setting, vehicles and other equipment may be contaminated with virus from the infected animal and then contact other susceptible animals, movement of virus on people's footwear is also likely to transmit virus. However, climatic conditions in the area (hot and dry) will limit the survival time of the virus on inanimate objects. Humans can play a significant role in transmitting virus from place to place either through their work (vets investigating one outbreak may transmit disease to another area if sufficient biosecurity is not practiced) or through social activity (for example, visiting other farms/herds, visiting livestock markets, etc.).
Aerosol	Negligible	A single infected bovine animal is unlikely to excrete sufficient virus on the breath to allow airborne spread beyond very close contact, and climatic conditions in this area would also make this route very unlikely

Factors attributable to the hazard (taken from Murray, *et al.*, 2010)

The following consequences should be considered and discussed during a consequence assessment

Direct consequences

a) Outcome of exposure in domestic and wild animals and their populations:
   - Biological (morbidity and mortality, sterile immunity, incubatory or convalescent carriers, latent infection)
   - Production losses

b) Public health consequences

c) Environmental consequences
   - Physical environment, such as 'side effects' of control measures
   - Impacts on other life forms, biodiversity, endangered species

Indirect consequences

a) Economic considerations
   - Control and eradication costs
   - Compensation
   - Surveillance and monitoring costs
   - Costs of enhanced biosecurity services
   - Domestic effects (changes in consumer demand, effect on related industry)
   - Trade losses (embargoes, sanctions, market opportunities)

b) Environmental:
   - Reduced tourism and loss of social amenity

While the above factors are taken from guidelines on import risk analysis, many of them will also be relevant to risk analysis applied to livestock movements.

When evaluating the magnitude of consequences and the likelihood of consequences occurring at that magnitude, you may describe a small number of outbreak scenarios. The relative likelihood of each of these occurring can then be estimated along with the likely magnitude of the consequences in each case (Murray, *et al.*, 2010).

An example of possible outbreak scenarios after an infected animal enters a livestock market in Central Myanmar, for example, might include:

1. Disease does not establish in the market
2. Disease establishes in the market but the infected animal is recognised and no animals permitted to leave the market.
3. Disease establishes in the market, is not recognised and animals move freely out of the market

The likelihood of each scenario occurring and the consequences of each scenario can then be described and, when using qualitative assessment, each scenario can be assigned a level of likelihood and a level of consequence, i.e. negligible, very low, low, medium, high, severe, etc.

Examples of some consequence assessments are provided by (APHIS, 2013 and Lyytikäinen, et al., 2011), the former using a detailed descriptive version of a consequence assessment, while the latter uses a complex modelling approach.

Risk estimation

The risk estimation summarises the results of the entry, exposure and consequence assessments. For import risk analysis, a specific structure should be followed in order for the risk estimation to be transparent and acceptable to various interested parties involved in trade decisions. However, where risk assessments are being conducted for other purposes (disease control, identifying critical control points, etc.), this section may be used to summarise the results of the risk assessment and bring together the results from each of the entry assessment, exposure assessment and consequence assessment into an overall conclusion.

Risk management

Risk management is the step in the risk analysis process where control measures (or risk mitigation measures) are decided upon and implemented. Where risk analysis has been conducted for livestock movement pathways, for example, certain points in those pathways may have been identified as 'high risk' compared to others. These can be referred to as 'critical points'; that is, where control measures may be targeted and have greatest impact on the risk of FMDV transmission through a particular pathway.

When considering risk mitigation measures, it is important to consider the stakeholders in the livestock movement pathway likely to be affected by the control measures and whether the impact of disease outbreaks on each of the stakeholders will justify the impact of the control measures. Where this is not the case, compensatory mechanisms might be necessary.

Understanding the stakeholders involved in animal movement pathways is important for risk analysis, and is addressed specifically in a related area known as value-chain analysis. Some further information can be found on application of value-chain analysis and risk analysis in a later section of this manual and in references at the end of this chapter.

Risk communication

While risk communication is listed here as the final step in a risk analysis process, it should in fact be conducted throughout the risk analysis process and includes communication with any individual or organisation affected by the risk analysis and its outcome. Where risk analysis is used for animal health decision making, people involved

CASE EXAMPLE: RISK ASSESSMENT *(P.R. China)*

Risk assessment of withdrawal of compulsory immunization for FMD serotype Asia I in P.R. China

Since May 2009, no clinical cases of Asia I FMD occurred or monitored in P.R. China. Individuals and herds antibody qualified rate of susceptible animals have been maintained at more than 80%. In this case, the Veterinary Bureau of the Ministry of Agriculture decided to carry out a risk assessment in 2016 for stopping compulsory immunization of Asia I FMD, to study the occurrence risk after the immunization exits.

The propagation dynamics model was built and simulated using MatLab software. This model calculated the transmission thresholds, outbreak probability, outbreak scale of the Asia I FMD under the implementation of immune measures and immune exit conditions.

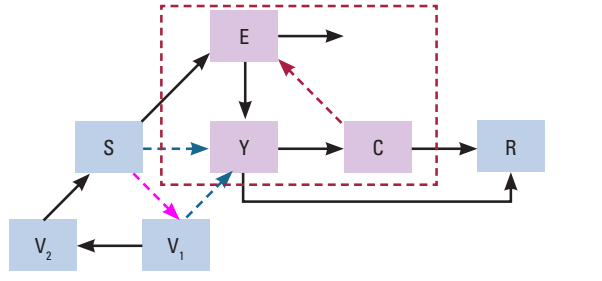

Figure A: The flow diagram of Foot and Mouth Disease (FMD) in various farms

Simulation results show that, under current conditions, the mathematical expectation of prevalence of Asia I FMD is less than 0.01% (confidence level is 99.99%). For epidemic spots, the prevalence of FMD caused by Asia I in the next five year is less than one over one hundred thousand (1/100,000), with or without immunization. The risk is expected to get lower as time passes until the risk of Asia I FMD outbreak is almost negligible.

After withdrawal of the Asia I FMD immunization, and the other control measures remain unchanged, the basic reproductive number (R_0) will increase from 0.597 (95%CI: 0.594-0.6) to 2.89 (95%CI: 2.88-2.9). If Asia I FMD outbreak occurred again, the risk of transmission and spread will be much higher than that of current immunization.

in risk communication should be those who are (or could be) affected by the disease in question, or by any control measures which might be implemented as a result of the risk analysis. Where the results of a risk analysis might affect the general public, they should also be included in the risk communication process.

Documentation of the risk analysis process is part of risk communication and the description should be detailed and transparent and include information on data used (including limitations in that data and any assumptions used) and clear justification for any control measures implemented as a result of the risk analysis.

Consultation with stakeholders during the risk analysis process, such as using focus groups during data collection, will also contribute to risk communication.

What information is needed when conducting a risk analysis?

A wide range of information is needed in order to conduct a risk analysis relevant to FMD, including (but not restricted to):

- Epidemiology of FMDV in the areas of interest
- Livestock husbandry systems in target areas
- Population and density of susceptible livestock species in target areas
- Prevalence/incidence of FMD in areas relevant to the risk analysis
- Livestock movement pathways destined for certain areas
- Volume of trade along particular movement pathways (number of animals being moved over a specific time period)
- The existence and volume of unofficial animal movement
- Methods of transportation (including time taken moving from A to B)
- Seasonal changes in volume of livestock traded
- Seasonal differences in outbreaks
- Individuals and organisations along the risk pathways identified
- Any existing risk mitigation strategies/control measures already in place
- Survival of FMD virus under conditions in the area where the risk analysis is being conducted (climatic conditions)
- Likelihood that FMD infected animals will show clinical signs

Data available

The data available on the categories outlined above is highly variable and often limited in this region. However, incomplete data at the start of a risk analysis should not prevent conduct of risk analyses. It will, however, influence the type of risk analysis conducted and the sources of data used to inform that risk analysis.

The use of quantitative risk assessments generally requires high quality and detailed data in order to produce a meaningful result. Therefore, where this data is not available, qualitative assessments should be used. However, regardless of whether a qualitative or a quantitative approach is used, it will be necessary to gather data in order to conduct a risk analysis. The following lists provide examples of existing sources of data which might be available, as well as data collection methods which could be applied during the risk analysis process. Again, this list is intended as a guide and is not exhaustive:

Existing sources of data:

- Disease reporting systems (ARAHIS, WAHIS, National outbreak report data, etc.)
- Outbreak investigation reports
- Laboratory records
- Livestock population data
- Climate data
- Published risk assessments, papers on epidemiology of FMD
- Livestock movement records
- OIE Terrestrial Animal Health Code
- Surveillance studies conducted for other reasons

Data collection:

- Field studies (questionnaires for livestock producers, traders, government vets and other stakeholders)
- Surveillance studies
- Focus groups/expert opinion

There are limitations to all types of data used, but again this should not prevent us from proceeding with a risk analysis. However, the risk analyst should carefully consider the data used for a particular purpose and clearly outline the limitations and any assumptions made when using data in a risk analysis.

The reference list at the end of this chapter provides several examples of risk analyses which use different types and sources of data. Studying published risk analyses provides a good insight into the sources of data used, together with the strengths and limitations of that data. Reading previous risk analysis documents will also demonstrate how authors describe their reasons for using certain data and the limitations of the data.

It is important when writing up a risk analysis that the source of data and limitations within that data are described in detail so that the process is transparent and the reader can understand the strengths and limitations of the risk assessment.

Variability and uncertainty

While considering data needed for a risk analysis, it is pertinent to describe the terms 'variability' and 'uncertainty' as these terms are used frequently in risk analysis.

All risk analyses will contain variability and uncertainty in the data they use. The former is the inherent variation in biological systems (such as varying incubation periods between different animals infected with the same virus). Variability can be managed by standard statistical procedures (further description of these is beyond the scope of this chapter, but the reader is referred to published quantitative risk analyses listed in the reference section). Uncertainty, in contrast, indicates ignorance or incomplete information (i.e. a lack of knowledge of the disease status in a country) (Thrusfield, 2007). Variability will exist even where there is complete knowledge. All variability and uncertainty, and how it has been managed, should be clearly described in the risk analysis document. Again, it is helpful to look at how authors of previous risk analyses have dealt with variability and uncertainty and the reader should refer to the publications listed in the reference list.

Value Chain analysis

Value chain analysis is mentioned here as it can be used in combination with epidemiological risk assessment when addressing livestock disease management. According to FAO (2011), the combination of value chain mapping and economic analysis with epidemiological risk analysis is useful in national (or local) animal health planning to:

1. Assess the epidemiological and socio-economic justification for different disease control strategies.
2. Inform the stakeholders involved in the different disease control strategies.
3. Evaluate the socio-economic impact of contagious diseases and different control strategies on the different stakeholders affected.
4. Plan adjustments to control strategies based on the results obtained from the epidemiological and socio-economic assessments.

While a detailed description of value chain analysis is beyond the scope of this chapter, the following are useful references on this subject: (FAO, 2011 and FAO, 2012). It

is recommended that the reader refer to these documents as they help not only to understand how risk analysis and value chain analysis can work together, but also provide good contextual information on the application of risk analysis to animal health problems.

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Risk analysis for Foot and Mouth Disease

World Organisation for Animal Health
12, rue de Prony
75017 Paris, France
Tel.: 33-(0)1 44 15 18 88
Fax: 33-(0)1 42 67 09 87

www.oie.int

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