

CHAPTER 7

MODELING A FMD OUTBREAK IN TULARE COUNTY

The value of animal health surveillance and monitoring services equals the expected losses they prevent. Even though catastrophic losses can be caused by a number of exotic animal diseases, in this study the losses arise exclusively from an assumed FMD outbreak that starts in the South Valley and, eventually, involves the entire San Joaquin and Chino Valleys. Hence, the estimated value should be considered a lower bound of the true economic value of animal health surveillance and monitoring services.

These expected losses are defined as the estimated cost of the outbreak times the probability of occurrence. The FMD virus could be introduced into California through a number of routes (the most important are travelers, uncooked garbage, economic terrorism, and imports of animals and animal products). Since the risk involved in each of these routes varies over time due to changes in regulations and technical change, there are no up-to-date estimates of risk levels. Estimation of the true risk levels is important because they provide valuable information to update trade regulations and target surveillance activities. However, such estimation effort would require resources in excess of those available for this research. To increase the efficiency of monitoring and surveillance services, estimation of the risk of introduction of FMD virus through alternative routes should be considered.

The model assumes that all susceptible species in the South Valley are affected by the outbreak. In regions where FMD is endemic, outbreaks occur irregularly in time and magnitude, making it very difficult to derive general properties and predictive values. Even among fully susceptible populations, some animals are not infected.⁹ Also, it is impossible to know beforehand whether any particular strain of FMD would affect all susceptible species or only some. However, considering the high density production conditions in the South Valley, all susceptible animals should be considered at risk.

The dissemination of the disease depends on a number of factors: weather patterns, animal densities both on farms and at the regional level, production practices, direct contacts between susceptible animals, indirect contacts (e.g., through humans, non-susceptible wildlife or materials such as feed trucks), and control policies (stamping out was the only control analyzed in this study).

⁹ As was the case in the 1977 outbreak in Taiwan which affected exclusively pigs and not other susceptible species (Dunn and Donaldson, 1997; Shieh, 1997).

This chapter reviews the construction of the model used to estimate potential losses—in other words, to evaluate the losses that could be avoided or reduced by the action of monitoring and surveillance services. The chapter includes a description of:

- Physical characteristics of the South Valley that may affect the spread of a FMD outbreak—weather patterns, roads and other geographic circumstances, etc.
- The risk factors identified in the study.
- The simulation model and its two components: an epidemiological model and an economic model (the two models are described in detail in Appendices B and C).

Physical characteristics

Large hog facilities, feedlots and dairies in the study area are located in several clusters with high concentrations of susceptible animals. Under these conditions airborne diffusion of FMD becomes a major concern, and weather is a major influence on airborne diffusion. The virus cannot survive when relative humidity is below 60% or temperature is high (Moutou and Durand, 1994). Donaldson and Ferris (1975) showed that, provided relative humidity was higher than 60%, neither daylight nor other environmental factors greatly influenced virus survival. Relative humidity in the South Valley is above 60% during daylight hours most days except in the summer and almost every night throughout the year.

Winds in the San Joaquin Valley have a clear seasonal pattern. April, May and June each average about three days of moderate winds, above 7.2 km/h. April, May, June and July each have between two to three weeks of slow winds, faster than 3.6 km/h and slower than 7.2 km/h. Finally, a slow breeze of less than 3.6 km/h predominates—more than three weeks per month—between September and February. The wind direction also presents a clear seasonal pattern. Northern winds are more common between October and December—between six and nine days per month. Northwesterly winds predominate between April and August—between 12 and 17 days per month—while southern or southeastern winds predominate in September and October.

In summary, weather conditions in the South Valley would allow airborne diffusion all year. During the summer months, the spread would occur during the night hours when humidity is higher and the temperature lower. In other seasons, conditions could be suitable for airborne diffusion all day.

There are no major geographic features in the South Valley that could hinder airborne diffusion of the virus. A few dairies are surrounded by orchards, but the trees are relatively low and would not be an efficient barrier to massive movement of aerosols. Most of the dairies are surrounded by open spaces with pastures or annual crops.

Two major north-south highways—Highways 5 and 99—cross the South Valley. Neither could be completely closed to enforce quarantines because of disruption to other economic and social activi-

ties. Control on these roads could only be partial, blocking the movement of large animals. Also, it would be impossible to completely control the movement of small animals or farmers and other people in close contact with susceptible animals.

Risk factors

Factors affecting the spread of a FMD outbreak in the South Valley can be categorized as high and low risk.

High risk factors are:

- Climatic conditions in the San Joaquin Valley, which allow airborne spread all year round.
- High density of susceptible animals within premises as well as in the whole region. Very large dairies (above 3,000 cows) and hog operations (above 1,000 animals) present a particularly high risk.
- Lack of awareness about FMD, which could lead to a wrong diagnosis of the first cases.
- Difficulty in reconstructing all movements in and out of farms during the days prior to diagnosis of the outbreak.
- Lack of available funds for timely depopulation of infected premises.
- Difficulty in completely enforcing the quarantine along the two major highways that cross the South Valley.
- Movement of people, neighbor dairymen in particular, to other premises with susceptible animals.
- Animal movements between premises—from dairy to dairy, from dairy to calf ranch, from dairy to stocker operation.
- Backyard operations with no animal health control where people also work in a commercial operation with susceptible animals.
- Services entering several farms on the same route without proper sanitary controls.
- Milk movements, mainly from farm to plant, with milk trucks stopping in several dairies during the same trip.
- Movement of cull cows to other dairies.
- Culling of sick cows without proper veterinary diagnosis.
- Movement of hogs from slaughterhouses to hog farms.
- Use of rejected milk as animal feed.

54 Potential Impact of Foot-and-Mouth Disease in California

- Wildlife population in close contact with livestock in the Valley, in particular rodents, birds and stray dogs.

Low-risk factors are:

- Milk movements, mainly from farm to plant, with milk trucks stopping in one dairy in each trip.
- Services visiting several farms in the same route without proper sanitary controls (if they do not enter the premises).
- Reduced use of emergency veterinary services, and faster culling of sick cows.
- Use of uncooked garbage as animal feed.
- Control of run off water.
- Backyard operations with no animal health control (if the owner does not work in a commercial operation with susceptible animals).
- Inadequate sanitary inspection of animals entering fairs and shows.
- Environmental regulations that may delay depopulation of infected premises.
- Employees in several premises (saleyards, dairies, etc.) coming into contact with susceptible animals away from their employment.
- Wildlife population in close contact with livestock in the foothills.
- Court orders that may delay depopulation procedures.
- Negative publicity and action by animal rights activists that may delay depopulation procedures.

The importance of all these factors in the South Valley is increasing due to (1) expansion of the dairy industry and decline of the beef industry, leading to higher on-farm and regional animal densities, (2) new technologies with strong economies of scale that give an economic advantage to large facilities, (3) more hog farms in the area, (4) more use of separate facilities to raise replacement heifers, (5) more interstate movement of cattle, and (6) more interaction between farms in the South Valley and the foothills.

The model: two components

The dairy and livestock industries are linked forward and backwards to a number of industries, i.e., input suppliers, service providers, and milk and livestock buyers. A serious disruption of the dairy and livestock industries would also affect the linked industries. These are the indirect effects of the outbreak. The reduced economic activity would also reduce employment, sales and consumption throughout the economy; these are the induced effects.

The total estimated cost of the outbreak—including direct, indirect and induced effects—is calculated in this study by a model with two components: an epidemiologic module that simulates the diffusion of the outbreak, and an economic module that estimates the economic impact.

The epidemiologic module is built as a state-transition model representing the spread of FMD in California susceptible animal populations. It is a random state-transition model developed from a Markov chain. Similar models have been used by several authors to simulate FMD outbreaks (Miller, 1979; Dijkhuizen, 1989; Berentsen et al., 1992b; Garner and Lack, 1995).

Because the potential behavior of FMD under current conditions in California is unknown, the model used to generate the scenarios was based on (1) a review of production conditions in the South Valley, (2) overseas experiences and (3) expert opinions.

Chance has been postulated as a major factor affecting the magnitude of an outbreak (Carpenter, 1988a; Garner and Lack, 1995). Therefore, a stochastic model was constructed. All dissemination rates are allowed to change randomly in both directions up to a maximum of 30%. The mean and standard deviations of the number of animals in each state (susceptible, infected, etc.) are estimated after 100 runs.

Even though there is evidence that some strains of the FMD virus have developed specific infectivity for particular species, in this study it is assumed that all susceptible animals in the quarantine area can be infected. This is because, in the particular conditions of the South Valley, the potential for an extremely fast spread of the infection is so great that it becomes too risky to delay depopulation until completion of the tests to determine whether the strain has specific infectivity.

Only premises with cattle or pigs are included in the model. Since all other susceptible animals—sheep, goats, llamas, wild animals, etc.—are not important from an economic perspective or in the logistics of depopulation, the only role of these animals is as vectors. Their role in the epidemic is considered in the estimation of the dissemination rates.

The basic scenario is constructed on the assumption that the infection starts in a backyard pig operation. (No assumptions were made as to how the virus arrived there.) The epidemiological model simulates the spread of FMD in five different types of premises: large dairies (2,000 head average), small dairies (500 head average), feedlots (15,000 head average), and commercial hog facilities (500 head average) as well as backyard pig operations (one pig). The unit of analysis is the herd.

The state-transition model has two components: states and transition probabilities. The states are the different categories in which herds can be, e.g., susceptible to the disease, latent, infected with the disease, or dead as a result of the disease.¹⁰ The number of susceptible, latent and depopulated herds in each period depends on the control strategies.

¹⁰ If vaccination was considered or the disease was allowed to run its course, a fifth category would be immune.

The transition probabilities represent the probability that an individual will move to state j in the next period when it is presently in state i . The probabilities depend on production and environmental conditions, and on control strategies. Consequently, transition probabilities adequate to the particular production conditions and geographical distribution of herds in the South Valley were used.

The state-transition model used in this study has the following characteristics:

- States and transitions are discrete (e.g., one every half week).
- There is a finite number of states.
- Transitions depend only on the current state, not on prior states. In other words, the whole history of the process is contained in the current state.
- Some transition probabilities are a function of the state of the system in the current period.
- Within each herd, there is a random mixing of susceptible and infected individuals.
- The infectious period is short and has constant length.
- The disease does not spread outside of California.
- The affected regions return to their pre-outbreak situation in terms of the number and composition of livestock enterprises and establishments.

The model estimates the numbers of latent infections as well as infectious premises. Since it is expected that depopulation of dangerous contacts will be a major constraint in the eradication of an outbreak in California, the transition *latent to infectious* was introduced to explicitly explore the consequences of starting depopulation at different stages of the epidemic. Different intervention dates are considered, and the costs associated with the disease are calculated for each date. The only eradication policy analyzed is stamping-out.

This approach differs from similar previous studies which analyzed the eradication of incubating herds by reducing the transition *susceptible to infectious* and increasing the transition *susceptible to depopulated*. When modeled in this way, the probability of eradicating dangerous contacts does not depend directly on the number of exposed premises, and the outcome of the policy thus depends on simultaneous changes to two transitions. The combination of these effects impairs the tracing of efficiency of eradication policies.

In order to account for the possible additional state (latent), the time unit used in this study is a half week. This interval is only half as long as those reported in the literature, in particular for the infectious state. The model shows that even with this shorter interval the outbreak of FMD spreads extremely rapidly due to the intensive production conditions and to the regional high density of animals. Increasing the length of the infectious period would increase the rate of spread. This model,

therefore, provides a conservative estimate of the behavior of the infection.

Key disease parameters for the model are (1) incubation and latent period, (2) infectious period, (3) immune period, and (4) dissemination rate. Dissemination rates were set to reflect the intensive production practices and environmental conditions prevailing in the South Valley. These key disease parameters, dissemination rates in particular (including the assumed role of airborne diffusion), are described in detail in Appendix B.

Epidemiological assumptions

Three major assumptions of this report are that:

- The outbreak is successfully contained within California's borders. Thus trade restrictions are the only consequences felt by livestock industries outside California.
- The disease is eradicated in a limited period of time; in other words, it does not become endemic.
- The outbreak is a one-time event; in other words, the disease is completely eradicated after the outbreak.

The first assumption is very unlikely. Considering the animal movements between California and other states, it is highly probable that the outbreak will spread to other states even before it is diagnosed in California. However, a complete modeling of the U.S. livestock industry is beyond the scope of this study. The second assumption has higher probability. The high costs resulting from FMD becoming endemic and the feasibility of controlling animal movements make eradication the preferred option for almost every level of output prices and spread of the disease. The third assumption is an optimistic scenario because it supposes that C&D efforts can be 100% effective in eliminating the virus from all infected premises. The recent experience in Taiwan showed the extreme difficulty in eradicating the virus in a massive outbreak.

The extent and duration of the epidemic depend on (1) the delay before the disease is recognized, (2) the type of control strategy applied, (3) the availability of human and financial resources, and (4) the effectiveness of animal health authorities in executing the eradication policies. In the U.S. and California, the preferred option in dealing with a FMD outbreak is stamping-out. This would involve prompt and rigid control of the movements of animals and animal products, vehicles, equipment and people; prompt depopulation of infected or exposed premises; intense surveillance of suspected herds; and C&D of infected premises. The efficiency of this policy depends on the timely availability of sufficient human, physical and financial resources. If the policy cannot be implemented with a high degree of efficiency from the first moments, the final eradication cost may be higher than if alternative policies are implemented. Study of alternative policies, however, is beyond the scope of this project.

The economic model

The economic model, which is discussed in detail in Appendix C, has three components:

- The first calculates the direct cost of depopulation, C&D and quarantine enforcement.
- The second uses an input-output model of the California economy to estimate the value of the direct, indirect and induced losses caused by the outbreak.¹¹
- The third economic component estimates the losses caused by trade restrictions.

The first component includes both direct costs of eradicating the outbreak and production losses in the quarantine area in cattle, dairy, pigs, and related industries. Losses in other livestock industries, in wildlife and in outdoor activities are not included.

Depopulation costs are calculated for an individual animal; the total depopulation cost is then obtained by multiplying the cost per head by the average number of animals in each farm type and the number of premises in the category. Depopulation costs include compensation payments, the cost of killing the animals, and the cost of disposing of the carcasses; the latter can be heavy (see Appendix C). The cost of C&D per premise is estimated as the cost per representative premise times the number of infected premises in the category. Finally, the cost of quarantine enforcement is estimated on a regional basis. Production losses in the quarantine area arise from depopulation of infected premises and close contacts, and from the idle time until repopulation is allowed. The lost output for these premises is calculated as the average production per week times the number of weeks that the premises cannot be repopulated. It includes the value of the various products marketed, including beef from culled dairy cows. All costs were estimated with the collaboration of Veterinary Services (APHIS) and Animal Health Branch (CDFA) following the guidelines set by APHIS (1991).

The second component of the economic module—direct, indirect and induced losses in the state due to the reduced livestock and dairy output (estimated output losses)—is obtained by multiplying the estimated direct loss by the output multipliers in the input-output model. An input-output model for the state of California developed by M.I.G. Inc. was used (See Appendix C). Economic data used in the model for the dairy, beef cattle, swine and sheep industries are listed in Appendix A.

The third component, trade losses due to international trade restrictions, is estimated under the assumption that the U.S. will be able to export only in the FMD-endemic market for at least two years after the eradication of the last outbreak. The prices drop by 50%, but the volume exported is maintained. This is an unlikely scenario, since exports are likely to fall because of trade restrictions and output reductions. However, given the assumption that the outbreak is contained in California and the fact that California is a net beef importer, the volume of meat available for export from other states is assumed to remain unaffected.

¹¹ It is expected that the outbreak would spread very rapidly over several counties, making estimation of single-county costs almost meaningless.