A decision tree for optimising control measures during the early stages of a Foot and Mouth Disease epidemic

F.H.M. Tomassen, A. de Koeijer, M.C.M. Mourits, A. Dekker, A. Bouma, R.B.M. Huirne

Abstract

A decision tree was developed as a tool to support decision-making concerning control measures in the first few days following the declaration of an outbreak of Foot and Mouth Disease (FMD). The objective of the tree was to minimise direct costs and export losses of FMD epidemics in several scenarios. These scenarios were based on important determinants in the development of epidemics and therefore defined by livestock and herd density in the outbreak region, the possibility of airborne spread, and the time between first infection and first detection.

The starting point of the tree was an epidemiological model based on a deterministic Susceptible-Infectious-Recovered approach. The effect of four control strategies on FMD dynamics was modelled. In addition to the standard control strategy of stamping-out and culling high-risk contact herds, strategies were assessed involving ring culling within 1 km of an infected herd, ring vaccination within 1 km of an infected herd, and ring vaccination within 3 km of an infected herd. An economic model converted outbreak and control effects of farming and processing operations into estimates of direct costs and consequential export losses.

Results showed that animal density within the outbreak region is a very important determinant in deciding upon the economically optimal control strategy. Ring vaccination is the economically optimal control strategy for **densely** populated livestock areas whereas ring culling is the economically optimal control strategy for **sparsely** populated livestock areas.

12.1 Introduction

Foot and Mouth Disease (FMD) is a highly contagious disease that infects many cloven-footed mammals, including cattle, pigs, sheep, goats and deer. The virus has the potential to spread rapidly in susceptible populations. From previous economic studies it is clear that FMD outbreaks generate considerable losses due to costs of disease control and productivity losses as well as to constraints on the international meat and livestock trade (Power and Harris, 1973; Krystynak and Charlebois, 1987; Berentsen et al., 1992b; Garner and Lack, 1995; Mahul and Gohin, 1999; Mahul and Durand, 2000). Recent examples of the devastating consequences of FMD are the epidemics in Great Britain and The Netherlands in 2001. In Great Britain nearly four million animals were slaughtered and the disease spread to over 2030 livestock farms (Department for Environment, Food and Rural Affairs, 2001). During the Dutch epidemic about 265,000 animals had to be slaughtered and 26 farms were actually infected (Ministry of Agriculture, Nature Management and Fisheries, 2001). Another example is the epidemic which occurred in 1997 in Taiwan, in which more than four million pigs had to be slaughtered (Yang et al., 1999).

FMD is a difficult disease to control and eradicate because of the various mechanisms by which the virus can be transmitted (Sellers, 1971). The most common mechanism is the movement of infected animals to susceptible animals (Donaldson et al., 2001). Other mechanisms of spread include the movement of contaminated animal products such as meat, offal and milk. The FMD virus can also be transmitted mechanically, for example, by contaminated milking machines, by vehicles, especially those used for transporting animals, and by people. Another mechanism is airborne spread. Under certain epidemiological and climatic conditions the FMD virus can be spread by the wind. Of all mechanisms, spread by air is least controllable (Donaldson et al., 2001; Ferguson et al., 2001a; Sørensen et al., 2000 and 2001).

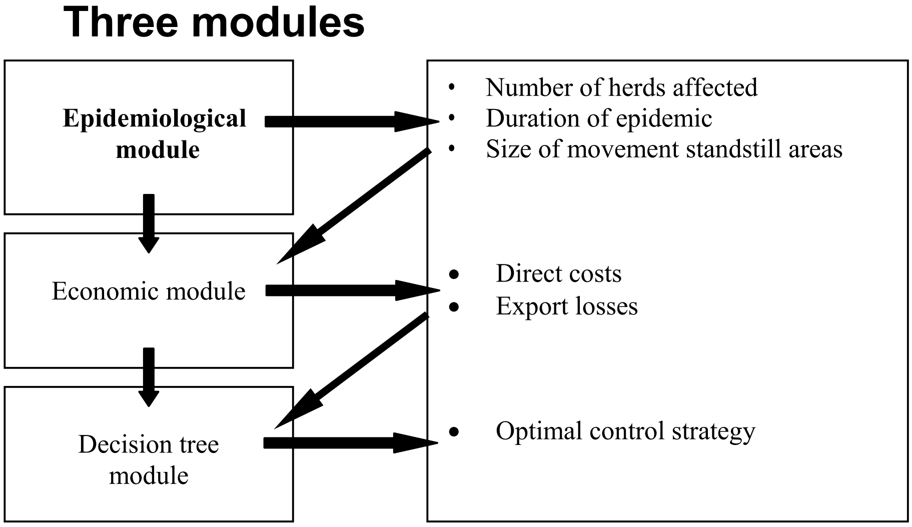
The objective of this study was to develop a tool to support decision-making on control strategies during the early stages of an FMD epidemic. The early stage means the first few days after the declaration of an outbreak. Successful eradication of an epidemic mainly depends on the selected control strategy and on the time interval between the diagnosis and implementation of the control strategy. Selecting an inadequate strategy may cause large additional economic losses (Mahul and Durand, 2000). Delayed implementation of control measures may cause extensive spread of the disease (Garner and Lack, 1995; Howard and Donnelly, 2000; Ferguson et al., 2001b). This means that it is very important for animal health authorities to make the right decision immediately following the initial diagnosis. Usually there is no time to gather additional data in order to support decision-making. Therefore, it is absolutely essential to have an overall analytical structure for these kinds of situations beforehand. This paper presents such an analytical structure, comprising a decision tree modelling approach using all information available in the first three days following the declaration of an outbreak. Using this approach the efficacy of disease control measures was evaluated in all kinds/types of scenarios. The efficacy was determined by modelling the epidemiological consequences and calculating the resulting direct costs and export losses. Scenarios were defined by important determinants in the development of epidemics that were found in the literature.

The objective of the decision tree was to be able to calculate the economically optimal control strategy for each scenario. Economically optimal meant that direct costs and export losses were minimised. The results from the decision tree may be used as yardsticks for deciding on control measures during possible FMD epidemics in the future.

12.2 Materials and methods

The modelling approach consists of three modules (see Figure 12.1): an epidemiological module to simulate the disease dynamics, an economic module to convert outbreak and control effects into estimates of direct costs and export losses, and a decision tree module to optimise decisions on control strategies. These modules are described in sections 12.2.5 to 12.2.7. Firstly the choice of virus strain, control strategies, regions and scenarios are outlined in sections 12.2.1 to 12.2.4.

Figure 12.1. An overview of the modelling approach



12.2.1 Choice of virus strain

There are seven immunologically and serologically distinct types of FMDV: A, O, C, SAT1, SAT2, SAT3 and Asia 1. Within each serotype there are several subtypes. The disease caused by different serotypes is clinically indistinguishable, although they vary somewhat in their epidemiological patterns (Sanson, 1993). Some strains of FMDV show a degree of natural adaptation to an animal species, with the result that the other species of animals appear to be more difficult to infect. An example of a pig-adapted virus strain was the strain that caused the Taipei China epidemic in 1997. No outbreaks were detected in cloven-hoofed animals other than pigs (Chen et al., 1999).

This study also confined attention to FMDV outbreaks in pigs, which is the source of most available data (Sellers, 1971; Salt et al., 1998; Yang et al., 1999). This data made it possible to quantify the FMD transmission between pigs and to estimate the efficacy of vaccination.

12.2.2 Control strategies

The size and duration of an epidemic depend largely on the control strategy implemented and on its effectiveness. In 1990/91 the EU decided to cease routine prophylactic vaccination. The control procedures are now total stamping out[4] of the disease in affected herds and movement control[5] in the surrounding area. These measures are laid down in Council directive 85/511/EEC. However, in certain circumstances these measures may need to be supplemented by other interventions such as ring culling[6] or ring vaccination[7]. In particular, outbreaks in areas containing high densities of susceptible animals and inadequate resources of manpower or plants for the slaughter and disposal of animals may spread out of control without additional control measures. In this context, ring culling and ring vaccination strategies target infection hotspots by reducing the density of susceptible herds in the vicinity of diagnosed infections, thereby removing the "fuel" essential to maintaining the epidemic (Scientific Committee on Animal Health and Animal Welfare, 1999; Ferguson et al., 2001a).

Findings from simulated FMD outbreaks in The Netherlands, Australia and France demonstrated that the strategy of stamping out and movement control alone (as laid down in 85/511/EEC) is rarely/almost never the economically optimal strategy. Extension of this strategy with culling of dangerous contact herds[8] generally reduced the epidemiological and

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[4] slaughtering of all the affected and in-contact susceptible animals of the infected herd

[5] prohibition of movement of animals and manure within a radius of 10 km of an infected herd

[6] slaughtering all susceptible animals within a certain radius of every newly diagnosed case of infection

[7] vaccinating all susceptible animals within a certain radius of every newly diagnosed case of infection

[8] slaughtering of herds that, although not showing FMD symptoms, are considered to be at high risk of spreading the disease because of proximity or contact with infected herds.

economic consequences (Berentsen et al., 1992b; Garner and Lack, 1995; Mahul and Durand, 2000).

Previous research, based on the Dutch Classical Swine Fever (CSF) epidemic of 1997-1998, showed that ring culling can also be an effective strategy for reducing the size of a CSF epidemic, if begun at an early stage (Elbers et al., 1998; Nielen et al., 1999; Stegeman et al., 1999). These studies suggested that 1 kilometre was an optimal radius from an epidemiological as well as from an economic point of view. A model analysis of the recent FMD epidemic in Great Britain (GB) showed that both ring culling and ring vaccination are potentially highly effective strategies if implemented sufficiently rigorously (Ferguson et al., 2001a). It was also concluded that ring vaccination policies need to be more extensive than comparable culling policies. In the case of infected but undiagnosed animals, culling eliminates virus replication by removing these animals. Vaccination only reduces the virus replication thereby limiting the transmission of the virus less effectively than culling (Sobrino et al., 2001). Another analysis of the British epidemic (Donaldson et al., 2001) concluded that ring culling is not always effective because of the very wide variation between different species in terms of the quantities of virus excreted, their susceptibility to infections, and the routes by which they are likely to be infected.

Based on the current EU legislation and previously discussed experiments and analyses of recent epidemics, the following interesting control strategies were considered in this study:
(1) Stamping out infected herds (85/511/EEC) and culling of high-risk contact herds (SO);
(2) SO extended with ring culling of all susceptible animals within a radius of 1 km of an infected herd (RC1);
(3) SO extended with ring vaccination of all susceptible animals within a radius of 1 km of an infected herd (RV1);
(4) SO extended with ring vaccination of all susceptible animals within a radius of 3 km (RV3).

All four strategies include movement control. The last three strategies also took into account the possibility of airborne spread outside implemented rings. Susceptible animals outside a ring but downwind of a virus plume were culled or vaccinated respectively. Vaccinated animals were culled as quickly as possible to keep the necessary period for regaining the status of an FMD-free country without vaccination as short as possible (see 2.6). Here, culling and destruction capacities were the restricting factors.

12.2.3 Regions

Studies have shown that a densely populated livestock area (DPLA) can give rise to the risk of major disease epidemics (Dijkhuizen and Davies, 1995). For this study The Netherlands has been divided into seven regions according to Stegeman et al.'s (1997) division method based on pig density per municipality. This method was useful for the epidemiological module, which calculated the transmission of a pig-adapted FMDV strain (see 12.2.1). Statistics were used from the year 1999 and pig densities were based on agricultural land area (Statistics Netherlands, 2001). According to this method, municipalities with more than 1000 pigs per km^2 were combined to form a pig-dense region. Municipalities that have fewer than 1000 pigs per km^2, but that are surrounded by densely populated municipalities were included in the pig-dense regions. Figure 12.2 shows the seven regions that could be distinguished. The very dark-coloured regions (regions 1, 2 and 3) have more than 1000 pigs per km^2. The other four areas are less densely populated.

Figure 12.2 Subdivision of The Netherlands into seven regions, showing density of pig population

Table 12.1 lists the densities of susceptible livestock species, herds and flocks per region and the mean sizes of herds and flocks per region. According to Michel et al.'s definition (2000)[9] the regions 1 through 4 are classified as DPLAs.

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[9] A DPLA for FMD contains >300 pigs per km^2 or >450 susceptible animals per km^2 (total land area).

Not only do animal densities vary between regions but the number of pig and cattle herds per square km also vary strongly. Region 2 has by far the most pig and cattle herds per square km. In this region the mean size of pig herds is small but the mean size of cattle herds is large because of a high concentration of veal calves in this area.

Table 12.1 Descriptive statistics for the regions

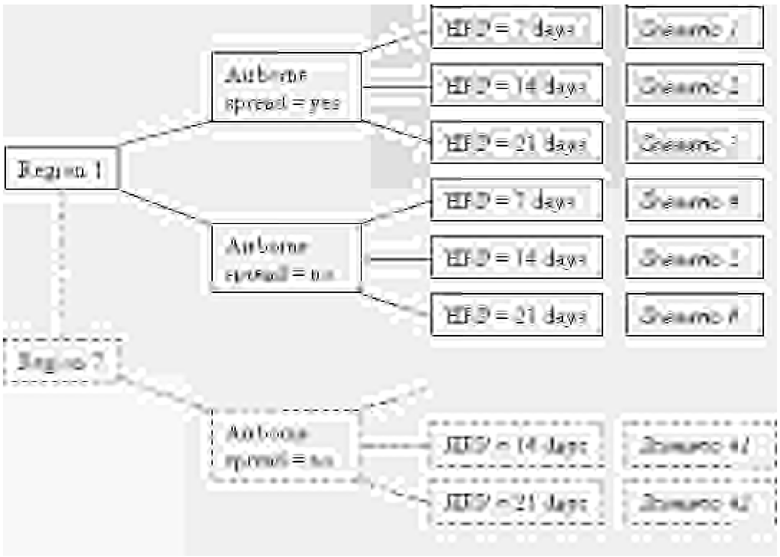
Region	1	2	3	4	5	6	7
Total livestock per:							
km^2 agricultural land	3019	2641	1633	1353	563	389	384
km^2 total land	1272	701	920	615	275	236	148
Pigs:							
Pigs/km$^{2\ a}$	2691	1736	1290	916	346	152	175
Herds/km$^{2\ a}$	2.30	4.56	2.32	1.24	0.41	0.19	0.31
Herd size	1171	381	555	738	851	798	559
Cattle							
Cattle/km$^{2\ a}$	279	838	305	336	166	178	129
Herds/km$^{2\ a}$	3.28	7.29	4.69	4.42	2.72	2.05	2.05
Herd size	85	115	65	76	61	87	63
Sheep							
Sheep/km$^{2\ a}$	30	47	31	84	42	55	76
Flocks/km$^{2\ a}$	1.11	2.24	1.48	2.55	1.56	1.20	1.77
Flock size	27	21	21	33	27	46	43
Goats							
Goats/km$^{2\ a}$	19	19	7	16	10	4	5
Flocks/km$^{2\ a}$	0.22	0.41	0.35	0.55	0.15	0.31	0.30
Flock size	85	46	20	29	65	13	15

a) per km^2 agricultural land

12.2.4 Scenarios

Scenarios were defined using important determinants in the development of epidemics that were found in literature. These determinants were: (a) livestock and herd density in the outbreak region (De Vos et al., 2000; Gerbier, 1999), (b) the possibility of airborne spread (Donaldson et al., 2001), and (c) the high-risk period (HRP) which is defined as the time interval between first infection and first detection (Horst, 1998). In Figure 12.3 each scenario is described by a region (which was described by livestock density and herd density), the possibility of airborne spread and the HRP.

Figure 12.3 Scenarios in the module



12.2.5 Epidemiological module

A mathematical model was constructed to estimate the effect of control strategies in the separate regions. A previously described deterministic Susceptible-Infectious-Recovered (SIR) model (De Jong, 1995; Stegeman et al., 1999) was applied to describe the transmission of FMDV between herds. In this model, S is the number of susceptible herds, I the number of infectious herds and R the number of recovered herds. Because herds are depopulated upon detection, R = 0 at all times in this study. In the model, the rate at which susceptible herds become infected can be described as: $C = \beta * SI/N$, in which C is defined as the number of virus introductions per unit of time into a susceptible herd, β as the infection rate parameter and N as the total number of herds. Furthermore, infected herds are depopulated at the rate $D = \alpha * I$, in which D is defined as the number of infected herds depopulated per unit of time and α as the depopulation rate parameter. The parameter α is the inverse of T, the average period that a herd is infectious. The transmission of FMDV between herds can be expressed as the herd reproduction ratio R_h, which is defined as the average number of outbreaks caused by one initial infected herd. The R_h can be estimated from $R_h = \beta / \alpha$ (Stegeman et al., 1999). From the definition of R_h it follows that if R_h is <1, the epidemic will fade out automatically. On the other hand, if R_h is >1, the virus will continue to spread (De Jong, 1995; Diekmann and Oosterbeek, 2000).

Knowledge and factual information about the precise transmission routes of FMD are scarce. This is in contrast to CSF (for example, see Stegeman et al. (1999) and De Vos et al. (in press)). Both diseases are list A diseases and spread via approximately the same transmission routes (Elbers et al., 1999; Donaldson et al., 2001; De Vos et al., in press). Therefore, to estimate the R_h, data collected during the Dutch CSF epidemic in 1997-1998 was used (Stegeman et al., 1999). Five transmission routes were distinguished by which the virus could be transmitted from one herd to another: animal transport, persons, neighbourhood, artificial insemination (AI), and rendering (Elbers et al., 1999; Stegeman et al., 2000). Three types of herds were defined: breeding herds, farrow-to-finish herds and finishing herds. The infectiousness of a herd was determined by the virus transmission within the herd (Van Nes et al., 1998). The parameters were adjusted to FMD using data collected from recent FMD outbreaks as well as data from transmission experiments (Sellers, 1971; Salt et al., 1998; Yang et al., 1999).

For each transmission route a transmission matrix was compiled in order to model the transmission from one herd type to another (Stegeman et al., 2000). These matrices combined the number of contacts with the estimated chance of transmission by a contact. The values in the transmission matrices were made dependent on herd density and mean herd size in the outbreak region concerned, as previously applied in Aujeszky and CSF control studies (De Koeijer and Stegeman, 2000; Stegeman et al., 2000).

Because the transmission routes were independent from each other, the five matrices could be added to one total transmission matrix. Subsequently the R_h was determined by calculating the dominant eigenvalue of the matrix. The matching eigenvector reflects the proportion of each herd type that became infected (Diekmann and Heesterbeek, 2000). The R_h was determined for each control strategy and each region. In the case of ring vaccination the assumption was made that transmission continued for one week following vaccination and that subsequently transmission ceased in vaccinated herds. The model was programmed in Mathematica 4.0 (Wolfram Research).

The main difference between transmission routes of FMD and CSF is that the FMD virus could be spread by wind over long distances under certain weather conditions[10] (Gloster et al., 1982; Donaldson et al., 2001), although opinions differ about the range of airborne spread. Air currents play a minor role as a transmission route between herds for CSF (Elbers et al., 1999; De Vos et al, in press). Therefore, airborne transmission was calculated separately, and was subsequently added to the R_h for the scenarios with airborne spread. (Gloster et al., 1982) For each combination of control strategy and region a worst case scenario of airborne spread was modelled (Gloster et al., 1981).

The calculated herd reproduction ratios were used in order to determine the number of herds affected, the duration of epidemics and areas subjected to movement restrictions for the

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[10] Most favourable conditions for airborne spread are a constant wind direction, a wind speed of 5 m/second, a high atmospheric stability, no precipitation, and a relative humidity above 55 % (Donaldson et al, 2001).

defined scenarios (see section 12.2.4). These outputs were then used as inputs to the economic module (see Figure 12.1).

12.2.6 Economic module

The purpose of the economic module was to quantify payoffs that could then be used in the decision tree module as the economic consequences of control strategies (see 12.2.7). Payoffs were defined as the direct costs and consequential export losses of the spread and control of an FMD epidemic. The direct costs were defined as the economic implications for (1) producers in the entire livestock value chain whose income depends on the livestock sector (e.g. farmers, abattoirs, hauliers and meat processors) and for (2) the government that is organising the disease control. Direct costs are generated by the implementation of control measures, such as costs of animal slaughter and vaccination, compensation payments and costs due to movement restrictions as well as idle production factors (Berentsen et al., 1992b). An epidemic could also have consequential export losses (Berentsen et al., 1992b; Garner and Lack, 1995; Mahul and Durand, 2000). These losses were defined as the value of livestock and livestock products that could not be exported because of trade restrictions due to the FMD epidemic.

In this module, the direct costs and consequential export losses were calculated in a rather objective way using several statistical databases (Statistics Netherlands, 2001; Product Boards for Livestock, Meat and Eggs, 2000; Product Board for Dairy, 2000). The module was programmed in Excel 97 (Microsoft Corporation).

12.2.6.1 Input data for direct costs

The economic module used the outputs from the epidemiological module (see Figure 12.1). To calculate the direct costs it used the number of affected herds, the duration of epidemics and the size of areas subjected to movement restrictions. The number of culled or vaccinated animals was also calculated. These calculations were based on livestock and herd densities in the outbreak region and the estimated number of contact herds, based on the calculated R_h, during the period between first infection and first detection. The duration of epidemics was longer when the culling and rendering capacity was not sufficient. The culling and rendering capacity was set at 16 farms per day for the SO and RC1 strategies and at 36 farms per day for the RV1 and RV3 strategies.

For each scenario, the direct costs were calculated as costs per dairy cow, sow or fattening pig that was either culled or put under movement restrictions. Input values for calculating the direct costs are represented in Table 12.2. These values were calculated based on statistics from the Agricultural Information and Knowledge Centre and Research Station for Animal Husbandry (2000) and estimates of the National Inspection Service for Livestock and Meat (Meuwissen et al., 1999). Organisation costs refer to costs of diagnosis, valuation of the animals, killing, cleansing and disinfecting of stables and equipment and surveillance in the protection and surveillance zones. Compensation payments are governmental payments to farmers whose animals were culled. These payments were calculated as the replacement values of the animals and feed supplies. Costs from idle production factors were calculated as the fixed costs decreased by released labour that could have been deployed elsewhere. The costs of movement restrictions were calculated as the costs for additional feed for maintenance and other supply and delivery problems because of the restrictions. Vaccination costs include labour and material costs of the vaccination teams (Mangen et al., 2001). For sheep and goats only the replacement values were included because a large number of these animals are kept as pets.

The losses for supplying, processing and distribution companies were calculated as half of the gross value added of agricultural production that did not take place due to the implemented control strategies. The distribution of the gross value added within the livestock production chain is shown in appendix III (Koole and Van Leeuwen, 2000).

Table 12.2 Input values for calculating the direct costs per dairy cow, sow and fattening pig (in €)

	Dairy cow (incl. young stock)	Sow (incl. piglets)	Fattening pig
Organisation costs	136	68	18
Compensation payments	1190	349	66
Idle production factors	4.95/day	0.66/day	0.14/day
Movement restrictions	0.07/day	0.15/day	0.02/day
Vaccination costs	9	7	2

12.2.6.2 Input data for consequential export losses

The extent of the consequential export losses depends on the duration and size of the epidemic and the reactions by importing countries during and after the epidemic. The studies of Mahul et al. (2000) and Berentsen et al. (1990) showed that import bans implemented by the importing countries play a key role in the evaluation of economic consequences of an FMD epidemic.

The duration and size of the epidemic resulted from the epidemiological module. For the possible reactions of importing countries two scripts were formulated. One script was based on OIE guidelines (see Table 12.3a).

According to the OIE International Animal Health Code, countries recover their status of FMD-free zone without vaccination after: (i) 3 months after slaughtering of the last infected herd when there is no vaccination strategy implemented but only stamping out and preventive slaughter or (ii) 3 months after slaughtering of the last vaccinated herd if a campaign of emergency vaccination is applied (Office International des Epizooties, 2000).

However, reactions of importing countries during and after epidemics in the past have indicated that these countries did not respect the OIE guidelines. For this reason, a more realistic script (REA) was defined, based on international trade restrictions applied during epidemics in the past (e.g. Italy, 1993; Greece, 1994; Great Britain and The Netherlands, 2001). The assumed import bans are mentioned in Table 12.3b. Assumptions on the duration of import bans were based on results of previous studies of Berentsen et al. (1990) and Mahul et al. (2000) and experiences of recent outbreaks (Commission Decisions 2001/172/EC and 2001/223/EC).

In both scripts three export product groups were distinguished: (1) livestock, (2) meat products and (3) dairy products. The importing countries were divided into a group of EU-countries and non-EU countries. Next, for each combination of product group and country group it was determined how long an import ban would be effective and whether the ban would be at a national or regional level. A regional import ban means an import ban for products coming from regions around infected farms in radii of 10 km. Because regional export data was unavailable, the assumption was made that exports were proportional to the regional production (Mahul and Durand, 2000).

Table 12.3a Import bans during and after an FMD epidemic in the OIE-script (OIE)

		During epidemic	After epidemic (days)	
			Regional	National
EU	Livestock	national	90	n.a.[a]
Meat		regional	90	n.a.
Dairy products		regional	0	n.a.
Non-EU	Livestock	national	90	n.a.
Meat		regional	90	n.a.
Dairy products		regional	0	n.a.

a) Not applicable

Table 12.3b Import bans during and after an FMD epidemic in the more realistic script (REA)

	During epidemic	After epidemic (days)	
		Regional	National
EU Livestock	national	180	n.a.[a]
Meat	regional	180	n.a.
Dairy products	regional	0	n.a.
Non-EU Livestock	national	n.a.	360
Meat	national	n.a.	360
Dairy products	regional	90	n.a.

a) Not applicable

12.2.7 Decision tree module

Rational economic decision-making models assume perfect markets and perfect information (Mileti, 1999). However, in reality animal health authorities are faced with sparse information about the probable efficacy of proposed control strategies. A decision tree analysis offers a formal, structured approach to decision-making, taking into account elements of uncertainty (Marsh, 1999). The aim is to make the chronological decision process explicit and to arrive at the best decision given the available information.

In this study the objective of the decision tree was to optimise early decisions for controlling FMD epidemics by calculating the economically optimal control strategy. A multi-attribute decision tree was built using the expected value criterion (Winterfeldt and Edwards, 1986). The two attributes were the direct costs and the consequential export losses and were weighted equally. For each scenario (see Figure 12.3) these attributes were calculated by means of the epidemiological and economic module.

In the early stages of a possible epidemic information is available on the outbreak region (livestock density and herd density) and the possibility of airborne spread (weather conditions). Information on the high risk period (HRP) is often sparse, because the source of introduction of FMDV in the primary-outbreak herd is often unknown and the analysis of virological and serological samples takes time (Horst, 1998). The decision tree method is used in two different situations: (1) if the HRP is known (see Figure 12.4a), and (2) if the HRP is unknown (see Figure 12.4b). In this last situation the probabilities of the HRPs were weighted equally. The trees were built in Data 3.5 (TreeAge Software, Inc.)

Figure 12.4a Decision tree if the HRP is known

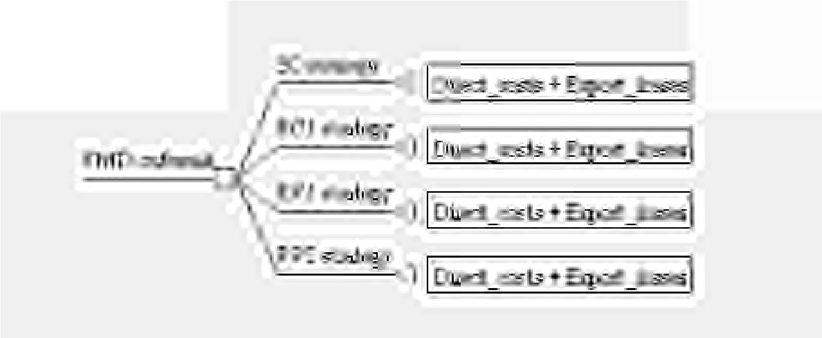
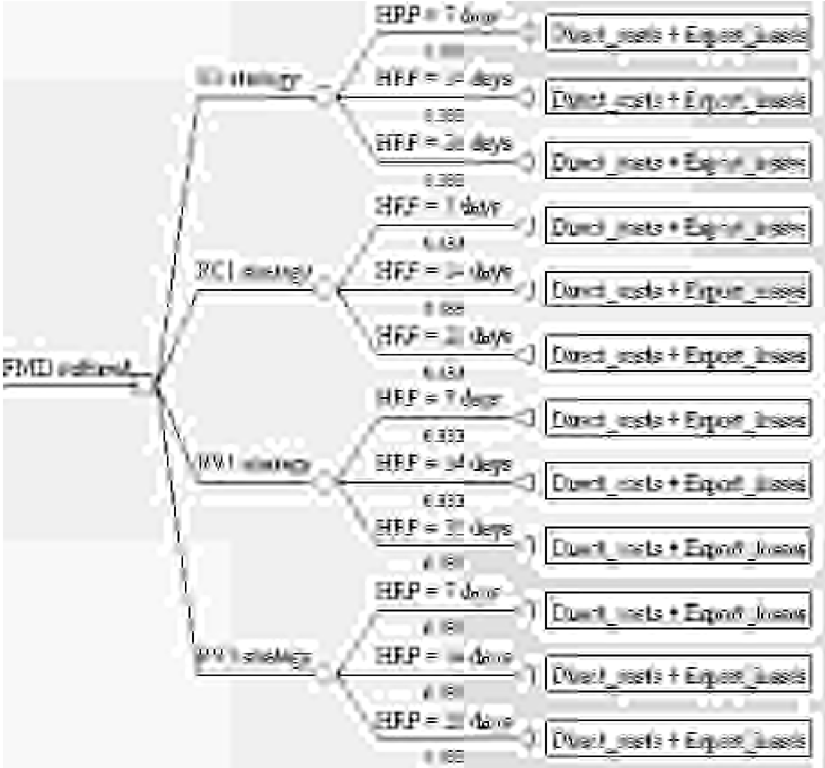


Figure 12.4b Decision tree if the HRP is unknown



12.3 Results

The epidemiological module simulated the disease dynamics, the economic module converted outbreak and control effects into estimates of direct costs and export losses, and finally a decision tree module optimised decisions on control strategies.

12.3.1 Epidemiological results

The epidemiological module generated the herd reproduction ratios (R_h) for each combination of region, control strategy and the possibility of airborne spread (see Table 12.4). When the R_h <1, exact numbers are not shown because the epidemic will fade out automatically. The results indicate that the SO-strategy is not adequate for stopping the epidemic in the regions 1, 2, 3 and 4 in the scenarios with airborne spread because the R_h is >1. Additional measures are necessary. In the other three regions the SO-strategy eradicates the virus because R_h is <1. With additional measures the R_h could be reduced and likewise the number of infected farms and the duration of the epidemic. In the case of airborne spread, the RC1-strategy is not very effective in region 2 either because of the high livestock and herd densities as well as the limited culling capacity. Ring vaccination is then the only option in this region for eradicating the virus.

Table 12.4 R_h for each region, control strategy and the possibility of airborne spread

Region		1	2	3	4	5	6	7
Without control		5.8	3.9	4.0	3.9	4.4	3.2	4.0
SO	airborne spread	2.0	2.7	1.7	1.1	<1	<1	<1
	no airborne spread	1.0	1.0	<1	<1	<1	<1	<1
RC1	airborne spread	<1	1.0	<1	<1	<1	<1	<1
	no airborne spread	<1	<1	<1	<1	<1	<1	<1
RV1	airborne spread	<1	<1	<1	<1	<1	<1	<1
	no airborne spread	<1	<1	<1	<1	<1	<1	<1
RV3	airborne spread	<1	<1	<1	<1	<1	<1	<1
	no airborne spread	<1	<1	<1	<1	<1	<1	<1

12.3.2 Economic results

The economic module calculated 336 times (42 scenarios per region * 4 control strategies * 2 scripts for possible import bans) the direct costs and consequential export losses of an FMD epidemic. To give an indication of the main results, the extremes in sizes and economic consequences within these 336 calculations are presented in Table 12.5.

In the regions 1, 2, 3 and 4 in the worst case scenarios the epidemic becomes endemic. These results also indicate that the export losses are much higher than the direct costs. This is valid for both scripts, although export losses in the OIE-script were lower than in the REA-script.

Table 12.5 Extremes in sizes and economic consequences of FMD epidemics in each region

Region		1	2	3	4	5	6	7
Duration (days)	Min	75	72	54	46	47	41	45
Max		end.[a]	end.	end.	end.	180	123	119
No. infected herds	Min	11	8	7	6	6	4	5
	Max	end.	end.	end.	end.	494	159	245
Movement control	Min	518	483	432	411	416	393	407
surface (km^2)	Max	end.	end.	end.	end.	10874	1500	2066
Direct costs	Min	83	60	36	24	16	4	5
(in million €)	Max	end.	end.	end.	end.	1478	63	110
Export losses (REA)	Min	563	443	453	407	314	315	339
(in million €)	Max	end.	end.	end.	end.	3051	678	926
Export losses (OIE)	Min	255	183	179	144	90	81	99
(in million €)	Max	end.	end.	end.	end.	2305	389	573

a) end. = the epidemic became endemic (duration > 1 year)

12.3.3 Results decision trees

The decision tree module was used in two different situations: (1) if the HRP is known and (2) if the HRP is unknown (see Figures 12.4a and 12.4b).

12.3.3.1 If HRP is known

The economically optimal and next-to-optimal control strategies for each region and HRP are shown in Table 12.6a (with airborne spread) and Table 12.6b (without airborne spread). These tables also present the Δ costs + losses, which is defined as the difference in direct costs and export losses between the optimal strategy and the next-to-optimal strategy.

These tables show that ring vaccination is always the economically optimal strategy in regions 1 and 2. The optimal radius of the ring vaccination depends on the length of the HRP. Ring culling is always the economically optimal strategy in regions 6 and 7. For the regions 3, 4 and 5 the economically optimal strategy depends on the length of the HRP and the presence of airborne spread.

The results of the two scripts of possible reactions of importing countries show almost the same rankings of economically optimal and next to optimal strategies. The differences in costs and losses between the economically optimal and next to optimal strategy generally increase as the HRP is extended.

Table 12.6a Optimal and next-to-optimal control strategies and the differences in costs and losses (in million €) between these strategies in the scenarios with airborne spread

Region	1	2	3	4	5	6	7
HRP = 7							
optimal strategy	RV3	RV3	RV1	RC1	RC1	RC1	RC1
next to opt. strategy	RV1	RV1	RV3	RV1	RV1	RV1[a]	RV1[a]
Δ costs + losses (REA)	51	11	5	61	35	49	49
Δ costs + losses (OIE)	35	9	3	52	32	45	44
HRP = 14							
optimal strategy	RV1	RV3	RV3	RC1	RC1	RC1	RC1
next to opt. strategy	RV3	RV1	RV1	RV1	RV1	RV3	RV1
Δ costs + losses (REA)	30	55	176	24	14	51	47
Δ costs + losses (OIE)	29	44	134	20	13	46	41
HRP = 21							
optimal strategy	RV1	RV3	RV1	RV3	RV1	RC1	RC1
next to opt. strategy	RV3	RV1	RV3	RV1	RV3	RV1	RV3
Δ costs + losses (REA)	405	766	241	90	5	134	61
Δ costs + losses (OIE)	404	746	236	71	3	62	51

a) OIE-script: SO

Table 12.6b Optimal and next-to-optimal control strategies and the differences in costs and losses (in million €) between those strategies in the scenarios without airborne spread

Region	1	2	3	4	5	6	7
HRP = 7							
optimal strategy	RV1	RV1	RC1	RC1	RC1	RC1	RC1
next to opt. Strategy	RV3	RV3	RV1	SO	SO	SO	SO
Δ costs + losses (REA)	7	10	51	46	24	14	24
Δ costs + losses (OIE)	5	7	42	33	20	11	39
HRP = 14							
optimal strategy	RV1	RV1	RV1	RC1	RC1	RC1	RC1
next to opt. Strategy	RV3	RV3	RV3	RV1	RV1	SO	RV1
Δ costs + losses (REA)	31	34	9	73	26	30	51
Δ costs + losses (OIE)	28	32	7	61	21	25	45
HRP = 21							
optimal strategy	RV1	RV3	RV1	RV3	RV1	RC1	RC1
next to opt. Strategy	RV3	RV1	RV3	RV1[a]	RV3	SO	RV3
Δ costs + losses (REA)	259	471	96	83	9	62	90
Δ costs + losses (OIE)	219	451	33	63	6	48	76

a) OIE-script: RC1

12.3.3.2 If HRP is unknown

The economically optimal and next-to-optimal control strategies for each region when the HRP is unknown are shown in Table 12.7. Ring vaccination is always the optimal strategy in the regions 1, 2 and 3 because ring vaccination reduces the number of infected herds and the duration of the epidemic.

Table 12.7 Optimal and next-to-optimal control strategies and the differences in costs and losses (in million €) between these strategies

Region	1	2	3	4	5	6	7
Airborne spread:							
optimal strategy	RV1	RV3	RV1	RV3	RV1	RC1	RC1
next to opt. Strategy	RV3	RV1	RV3	RV1	RV3	RV3	RV3
Δ costs + losses (REA)	128	268	23	25	4	81	56
Δ costs + losses (OIE)	132	256	38	21	1	69	48
No airborne spread:							
optimal strategy	RV1	RV3	RV1	RC1	RC1	RC1	RC1
next to opt. Strategy	RV3	RV1	RV3	RV3 [a]	RV1	RV3	RV3
Δ costs + losses (REA)	94	142	28	13	7	65	66
Δ costs + losses (OIE)	110	12	7	42	8	57	56

a) OIE-script: RV1

Ring culling is always the optimal strategy in regions 6 and 7. In these regions, ring vaccination prolongs the epidemic and enlarges the surface of movement standstill areas.

For regions 4 and 5 the optimal strategy depends on the presence of airborne spread.

The results of the two scripts of possible reactions by importing countries show almost the same rankings of optimal and next–to-optimal strategies.

12.3.3.3 Expected value of HRP information

Two extreme situations were examined; a situation with no HRP information at all and a situation with perfect HRP information. This made it possible to calculate the expected value of perfect information (see Table 12.8). The expected value of perfect information provides an upper limit for the expected value of information in general (Clemen and Reilly, 2000). The results in Table 12.8 emphasise the importance of retrieving information on the length of the HRP for the situations in which the expected value of perfect information is not zero. Gathering HRP information leads to better decision-making, particularly in regions 3, 4 and 5.

Table 12.8 Optimal strategies when HRP is unknown and known and the expected value of perfect HRP information (in million €)

Region	Airborne spread	HRP unknown	HRP known			Expected value of information
			7 days	14 days	21 days	
1	Yes	RV1	RV3 (-51)	RV1	RV1	17
	No	RV1	RV1	RV1	RV1	0
2	Yes	RV3	RV3	RV3	RV3	0
	No	RV3	RV1 (-10)	RV1 (-9)	RV3	6
3	Yes	RV1	RV1	RV3 (-176)	RV1	59
	No	RV1	RC1 (-51)	RV1	RV1	17
4	Yes	RV3	RC1 (-65)	RC1 (-33)	RV3	33
	No	RC1	RC1	RC1	RV3 (-121)	40
5	Yes	RV1	RC1 (-35)	RC1 (-14)	RV1	16
	No	RC1	RC1	RC1	RV1 (-85)	28
6	Yes	RC1	RC1	RC1	RC1	0
	No	RC1	RC1	RC1	RC1	0
7	Yes	RC1	RC1	RC1	RC1	0
	No	RC1	RC1	RC1	RC1	0

12.4 Discussion

12.4.1 Epidemiological module

This study used available knowledge to illustrate the epidemiological and economic consequences of an outbreak. For this reason, the model was restricted to a pig-adapted FMD virus strain. There was limited knowledge available on virus transmission in the field between other susceptible species. This means that the results can be interpreted as the optimal strategies for pig-adapted FMD virus strains. These results can be roughly extrapolated to other FMD virus strains. Control approaches for other strains would not differ much from the control approaches used in this study because all susceptible species were included in the control measures. Therefore, the economic results are likely to follow a comparable pattern as the results in this study.

12.4.2 Economic module

The economic module converted outbreak and control effects into estimates of direct costs and consequential export losses for producers in the livestock value chain and the government. An epidemic could also have effects on the Dutch economy as a whole because of the side effects of disease control measures (e.g. the closure of footpaths harms the tourist sector) and interactions between economic sectors (e.g. price drops for livestock products favours consumers) (Berentsen et al., 1992a; Garner and Lack, 1995; Mahul and Durand, 2000). These 'non-agricultural' effects have not been quantified because the aim was not to carry out a full social cost-benefit analysis. This analysis provides a framework for comparing disease control strategies but includes also difficulties. Many costs and benefits are by their nature difficult to quantify (e.g. emotional problems of farmers whose animals had to be culled). Assigning monetary values to these costs and benefits is a major problem of cost-benefit analysis and involves making subjective judgements (Ramsay et al., 1999).

A knowledge gap was found in the possible reactions of importing countries. Reactions do not always respect the OIE guidelines. This problem was solved by using two scripts for possible reactions. The model showed that varying lengths of import bans had only limited influence on the economically optimal control strategies. A limitation of the calculations is that these were based on changes in quantities due import bans. Price and substitution effects were excluded in the economic calculations. Therefore, the results provide upper bounds for the economic costs of an epidemic.

12.5 Conclusions

The decision tree is a useful tool for structuring and optimising early decisions concerning the control of FMD epidemics in different regions in The Netherlands. The outcomes can be used as yardsticks for deciding on control measures during possible FMD epidemics in the future. The results showed that not selecting the economically optimal strategy could cause large additional economic losses.

Animal density within the outbreak region is an important determinant in deciding on the optimal control strategy. The results show a considerable regional variation in the size of impacts. Ring vaccination is the economically optimal strategy for densely populated livestock areas because this strategy reduces the number of infected herds and the duration of the epidemic compared to the other strategies. Ring culling is the economically optimal strategy for sparsely populated livestock areas. For livestock areas that are neither very densely populated nor very sparsely populated, the optimal strategy depends on the length of the HRP and the presence of airborne spread.

The duration of an epidemic was one of the most important parameters, which determined the economic impact of an epidemic. This was consistent with previous research (Horst et al., 1999; Mahul and Durand, 2000). In densely populated livestock areas the culling and rendering capacity was the limiting factor, causing delays in culling and extension of the epidemic. Therefore, ring vaccination is the optimal strategy in these areas because it reduces the number of infected farms and likewise the duration of the epidemic.

The results of this study stress the importance of retrieving information on the expected length of the HRP as soon as possible after an outbreak of FMD has been declared, especially in regions that are neither very densely nor very sparsely populated.

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References

Agricultural Information and Knowledge Centre and Research Station for Animal Husbandry, 2000. *Quantitative information on livestock industry 2000-2001*. Research Station for Animal Husbandry, Lelystad, The Netherlands (In Dutch).

Berentsen, P.B.M., Dijkhuizen, A.A., Oskam A.J., 1992a. A critique of published cost-benefit analyses of foot-and-mouth disease. *Prev. Vet. Med., 12, 217-227*.

Berentsen, P.B.M., Dijkhuizen, A.A., Oskam A.J., 1992b. A dynamic model for cost-benefit analyses of foot-and-mouth disease control strategies. *Prev. Vet. Med., 12, 229-243*.

Chen, B.-J., Sung, W.H.T., Shieh, H.K., 1999. Managing an animal health emergency in Taipei China: foot-and-mouth disease. *Rev. sci. techn. Off. int. Epiz., 18 (1), 186-192*

Clemen, R.T., Reilly, T., 2000. *Making Hard Decisions with DecisionTools.* Duxbury Press, Belmont, California.

Commission Decision 2001/172/EC, 2001. Commission Decision of 1 March 2001 concerning certain protection measures with regard to foot-and-mouth disease in the United Kingdom and repealing Decision 2001/145/EC. *Official Journal of the European Communities, L62/22.*

Commission Decision 2001/223/EC, 2001. Commission Decision of 21 March 2001 concerning certain protection measures with regard to foot-and-mouth disease in the Netherlands. *Official Journal of the European Communities, L82/29.*

De Jong, M.C.M., 1995. Mathematical modelling in veterinary epidemiology: why model building is important. *Prev. Vet. Med., 25, 183-193*.

De Koeijer, A.A., Stegeman, J.A., 2000. Terminating Aujeszky vaccination in the Netherlands? *Vet. Res., 31 (1), 160-161.*

Department for Environment, Food & Rural Affairs, 2001. Http://www.defra.gov.uk.

De Vos, C., Horst, H.S., Dijkhuizen, A.A., 2000. Risk of animal movements for the introduction of contagious animal diseases into densely populated livestock areas of the European Union. In: Thrusfield, M.V., Goodall, E.A. (Eds.), *Proc. annual conference of the Society for Veterinary Epidemiology and Preventive Medicine*. *Edinburgh, 29-31 March 2000, 124-136.*

De Vos, C.J., Saatkamp, H.W., Huirne, R.B.M., Dijkhuizen, A.A., 2002. Conceptual framework to explore the risk of regional classical swine fever introduction in the European Union. *Rev. sci. techn. Off. int. Epiz., (in press).*

Diekmann, O. and Heesterbeek, J.A.P., 2000. *Mathematical Epidemiology of Infectious diseases: Model Building, Analysis and Interpretation*. John Wiley & Sons, Chichester.

Dijkhuizen, A.A., Davies, G., 1995. *Animal health and related problems in densely populated livestock areas of the Community. Proceedings of a workshop held in Brussels 22-23 November 1994.* Office for Official Publications of the European Communities, Luxembourg, report EUR 16609 EN.

Donaldson, A.I., Alexandersen, S., Sørensen, J.H., Mikkelsen, T., 2001. Relative risk of the uncontrollable (airborne) spread of FMD by different species. *Vet. Rec., 148 (19), 602-604*.

Elbers, A.R.W., Stegeman, J.A., Moser, H., De Jong, M.C.M., Ekker, H.M., Smak, J.A., De Leeuw, P.W., 1998. Effectiveness of preventive culling of pig herds during the Dutch CSF epidemic in 1997. In*: Proceedings of the 15th IPVS Congress, Birmingham, England, 5-9 July 1998, 271.*

Elbers, A.R.W., Stegeman, J.A., Moser, H., Ekker, H.M., Smak, J.A., Pluimers, F.H., 1999. The classical swine fever epidemic 1997-1998 in the Netherlands: descriptive epidemiology. *Prev. Vet. Med., 42, 157-184.*

Ferguson, N.M., Donnelly, C.A., Anderson, R.M., 2001a. The foot-and-mouth epidemic in Great Britain: pattern of spread and impact of interventions. *Science, 292, 1155-1160*.

Ferguson, N.M., Donnelly, C.A., Anderson, R.M., 2001b. Transmission intensity and impact of control policies on the foot and mouth epidemic in Great Britain. *Nature, 413, 542-548.*

Garner, M.G., Lack, M.B., 1995. An evaluation of alternate control strategies for foot-and-mouth disease in Australia: a regional approach. *Prev. Vet. Med., 23, 9-32*.

Gerbier, G., 1999. Effect of animal density on FMD spread. In: *Report of the session of the research group of the Standing Technical Committee of the European Commission for the control of foot-and-mouth disease held at Maisons-Alfort, France, 29 September - 1 October 1999, 17-25.*

Gerbier, G., Pouillot, R., Durand, B., Moutou, F., 2000. Modelling the effect of herd size on the herd probability of infection: application of the infection by airborne foot-and-mouth disease. In: Salman, M.D., Morley, P.S., Ruch-Gallie, R.R. (Eds.), *Proc. 9th symposium of the International Society for Veterinary Epidemiology and Economics, Breckenridge (Colorado), 6-11 August 2000.*

Gloster, J., Blackall, R.M., Sellers, R.F., Donaldson, A.I. (1981) Forecasting the airborne spread of foot-and-mouth disease. *Vet. Rec., 108 (17), 370-374.*

Gloster, J. Sellers, R.F., Donaldson, A.I. (1982) Long distance transport of foot-and-mouth disease virus over the sea. *Vet. Rec., 110 (3), 47-52.*

Hardaker, J.B., Huirne, R.B.M, Anderson, J.R., 1997. *Coping with risk in agriculture*. CAB International, Wallingford.

Horst, H.S., 1998. *Risk and economic consequences of contagious animal disease introduction*. Wageningen Agricultural University, PhD-thesis.

Horst, H.S., De Vos, C.J., Tomassen, F.H.M., Stelwagen, J., 1999. The economic evaluation of control and eradication of epidemic livestock diseases. *Rev. sci. tech. Off. int. Epiz., 18 (2), 367-379.*

Howard, S.C., Donnelly, C.A., 2000. The importance of immediate destruction in epidemics of foot-and-mouth disease. *Res. Vet. Sci., 69, 189-196.*

Koole, B., Leeuwen, M.G.A. van, 2000. *Het Nederlandse agrocomplex 2000*. Agricultural Economics Research Institute, The Hague, Report no. 1.00.12 (In Dutch).

Krystynak, R.H.E., Charlebois, P.A. (1987) The potential economic impact of an outbreak of foot-and-mouth disease in Canada. *Can. Vet. J., 28 (8), 523-527.*

Mahul, O., Durand, B., 2000. Simulated economic consequences of foot-and-mouth disease epidemics and their public control in France. *Prev. Vet. Med., 47, 23-38.*

Mahul, O., Gohin, A., 1999. Irreversible decision making in contagious animal disease control under uncertainty: an illustration using FMD in Brittany. *Eur. Rev. Agric. Econ., 26 (1), 39-58.*

Mangen, M.-J.J., Jalvingh, A.W., Nielen, M., Mourits, M.C.M., Klinkenberg, D., Dijkhuizen, A.A., 2001. Spatial and stochastic simulation to compare two emergency-vaccination strategies with a marker vaccine in the 1997/1998 Dutch Classical Swine Fever epidemic. *Prev. Vet. Med., 48, 177-200.*

Marsh, W., 1999. The economics of animal health in farmed livestock at the herd level. *Rev. sci. tech. Off. Int. Epiz., 18 (2), 357-366.*

Meuwissen, M.P.M., Horst, H.S., Huirne, R.B.M., Dijkhuizen, A.A., 1999. A model to estimate the financial consequences of classical swine fever outbreaks: principles and outcomes. *Prev. Vet Med., 42, 249-270.*

Michel, I., De Vos, C., 2000. Densely populated livestock areas in the European Union: definition and location. In: Tielen, M.J.M., Voets, M.Th. (eds.), *Proc. Xth International Congress on Animal Hygiene, Maastricht, The Netherlands, 2-6 July 2000, 332-337*.

Mileti, D.S., 1999. *Disasters by design. A reassessment of natural hazards in the United States*. Joseph Henry Press, Washington, D.C.

Ministry of Agriculture, Nature Management and Fisheries, 2001. http://www.minlnv.nl/infomarkt/parlemnt/2001/ par01150.htm

Nielen, M., Jalvingh, A.W., Meuwissen, M.P.M, Horst, H.S., Dijkhuizen, A.A., 1999. Spatial and stochastic simulation to evaluate the impact of events and control measures on the 1997-1998 classical swine fever epidemic in The Netherlands. II. Comparison of control strategies. *Prev. Vet. Med., 42, 297-317.*

Office International des Epizooties, 2000. *International Animal Health Code.* Office International des Epizooties, Paris. 9th edition, Http://www.oie.int.

Power, A.P., Harris, S.P. (1973) A cost-benefit evaluation of alternative control policies for foot-and-mouth disease in Great Britain. *J. Agr. Econ., 24, 573-597.*

Product Board for Dairy, 2000. *Statistisch Jaaroverzicht 1999*. Rijswijk (in Dutch).

Product Boards for Livestock, Meat and Eggs, 2000. *Vee, vlees en eieren in cijfers. Statistisch jaarrapport, uitgave 2000.* Rijswijk, rapport 0018 (in Dutch).

Ramsay, G.C., Philip, P., Riethmuller, P., 1999. The economic implications of animal diseases and disease control at the national level. *Rev. sci. tech. Off. int. Epiz., 18 (2), 343-356.*

Salt, J.S., Barnett, P.V., Dani, P., Williams, L., 1998. Emergency vaccination of pigs against foot-and-mouth disease: protection against disease and reduction in contact transmission. *Vaccine, 16, 746-754.*

Sanson, R.L., 1993. *The development of a decision support system for an animal disease emergency*. Massey University, Palmerston North, PhD-thesis.

Scientific Committee on Animal Health and Animal Welfare, 1999. *Strategy for emergency vaccination against foot-and-mouth disease.* Http://europa.eu.int/comm/food/fs/sc/scah/out22_en.pdf.

Sellers, R.F. (1971) Quantitative aspects of the spread of foot-and-mouth disease. *Vet. Bull., 41, 431-439.*

Sobrino, F., Sáiz, M., Jiménez-Clavero, M.A., Núnez, J.I., Rosas, M.F., Baranowski, E., Ley, V., 2001. Foot-and-mouth disease virus: a long known virus, but a current threat. *Vet. Res., 32, 1-30.*

Sørensen, J.H., Jensen, C.Ø., Mikkelsen, T., Mackay, D.K.J., Donaldson, A.I., 2001. Modelling the atmospheric dispersion of foot-and-mouth disease virus for emergency preparedness. *Phys. Chem. Earth (B), 26 (2), 93-97.*

Sørensen, J.H., Mackay, D.K.J., Jensen, C.Ø., Donaldson, A.I., 2000. An integrated model to predict the atmospheric spread of foot-and-mouth virus. *Epid. and Infect., 124, 577-590*.

Statistics Netherlands, 2001. *Statline.* Http://www.cbs.nl.

Stegeman, A., Elbers, A.R.W., De Jong, M.C.M., Oosterlaak, B., Dijkhuizen, A.A., 1997. Estimating the rate of pseudorabies virus introduction into pig-finishing herds at regional level. *Veterinary Quarterly, 19, 5-9.*

Stegeman, A., Elbers, A.R.W., Smak, J., De Jong, M.C.M., 1999. Quantification of the transmission of classical swine fever virus between herds during the 1997-1998 epidemic in The Netherlands. *Prev. Vet. Med., 42, 219-234.*

Stegeman, J.A., Elbers. A.R.W., Bouma, A. and De Jong, M.C.M., 2000. *Classical swine fever in the Netherlands 1997-1998. Epidemiological analysis.* ID-Lelystad, Report no. 2015 (in Dutch).

Van Nes, A., de Jong, M.C.M., Buijtels, J.A.A.M., Verheijden, J.H.M., 1998. Implications derived from a mathematical model for eradication of pseudorabies virus. *Prev. Vet. Med., 33, 39-58.*

Winterfeldt, D. von, Edwards, W., 1986. *Decision analysis and behaviourial research*. Cambridge University Press, Cambridge.

Yang, P.C., Chu, R.M., Chung, W.B., Sung, H.T., 1999. Epidemiological characteristics and financial costs of the 1997 foot-and-mouth disease epidemic in Taiwan. *Vet. Rec., 145, 731-734.*

Appendix III

Table III.1 Distribution of the gross value added (in billion €) within the livestock production chain (mean value of 1995 and 1998)

	Grassland based livestock farming		Intensive livestock farming		Total	
	Billion €	%	billion €	%	billion €	%
Livestock farms	3.0	41	0.7	22	3.7	35
Supply industry	1.4	19	0.7	22	2.1	20
Processing industry	2.2	30	1.3	40	3.5	33
Distribution industry	0.7	10	0.5	16	1.2	12
Total	7.3	100 %	3.1	100 %	10.5	100 %