STOCHASTIC AND SPATIAL SIMULATION OF CONTAGIOUS ANIMAL DISEASE OUTBREAKS

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Abstract: Contagious animal disease outbreaks are of great economic importance. Decisions on how to control outbreaks have to be made taking into account many uncertainties. A spatial and stochastic simulation model is presented that predicts the spread of foot-and-mouth disease for various regions and control strategies. The outcome has shown to be especially dependent on uncertain input parameters on disease spread and control strategy implemented.

Keywords: Animal disease control, Economics, Foot-and-mouth disease, Sensitivity analysis, Simulation, Uncertainty analysis

1. INTRODUCTION

To maintain trading relationships with countries inside and outside the borders of the European Union (EU), countries increasingly require the disease free status to be obtained and maintained, without applying preventive vaccination programs. Especially in major exporting countries, such as the Netherlands and Denmark, contagious animal disease outbreaks (e.g. foot-and-mouth disease) are understandably feared because of possible export bans. For that reason, countries implement many measures to prevent the introduction of contagious animal diseases. However, failure of this prevention is realistic as shown by recent outbreaks of classical swine fever in Germany and Belgium and foot-and-mouth disease in Greece. In cases where contagious outbreaks occur, the epidemic needs to be eradicated by rapid identification and elimination of all virus sources. Very important in effective control is setting the correct priorities.

Decisions regarding the control of this type of disease outbreaks comprise a large amount of uncertainty regarding the possible extent of the outbreak (size of the area and number of farms involved) as well as the possibility of export bans set by other countries (which countries, over what period of time, production banned from the entire country or from a region only). A set of models is being developed that calculate the technical and economic consequences of different control strategies for outbreaks of foot-and-mouth disease (FMD) taking into account these uncertainties.

The modelling approach requires simulation of (a) disease spread between farms, (b) direct costs of eradication and (c) indirect costs due to export bans. In that, simulation of disease spread serves as starting point for the economic calculations. Input parameters on disease spread are especially difficult to obtain, since (data about) epidemics of FMD are scarce. Furthermore, real-life experiments to evaluate different control strategies is impossible. And therefore, quantification of the uncertainties in the model output that result from uncertainties in the model input is absolutely essential.

This paper describes the spatial and stochastic simulation model for disease spread between farms and preliminary results of the sensitivity and uncertainty analysis of this model.

2. EpiMAN: DECISION SUPPORT SYSTEM FOR DISEASE CONTROL

The stochastic simulation model to evaluate different control strategies for FMD outbreaks will be part of a computerized decision support system for contagious animal disease control, called EpiMAN. EpiMAN has initially been developed in New Zealand (Sanson, 1993) and is currently modified to suit the situation in the European Union (EU) (Jalvingh *et al.*, 1995). These modifications take place within a project funded by the European Commission.

EpiMAN consists of a database management system, a geographic information system, simulation models and expert systems. EpiMAN can be used for the operational management of the outbreaks, but also for tactical/strategic management (Jalvingh *et al.*, 1995).

The operational management is involved with the daily management of the outbreak and focuses on setting the correct priorities for rapid identification and elimination of all virus sources (Nielen *et al.*, 1996). The tactical/strategic management part is aimed at policy makers who can use the model presented in this paper to conduct a series of what-if scenarios to investigate the likely consequences of major control policy options.

3. SIMULATION OF DISEASE SPREAD BETWEEN FARMS

3.1 Outline of simulation

FMD is an extremely infectious virus disease which can affect any cloven-hoofed animal and which spreads through different mechanisms (animals, people, vehicles, air). As set by EU law, preventive vaccination is not allowed. In case of introduction of FMD, rapid spread may occur. FMD should be eradicated by slaughtering and destroying affected herds and by installing additional controls, such as radial zones in which movements of animals, people and vehicles are restricted and tracing farms that had contact with infected farms. This is referred to as the basic EU strategy.

Starting point in the simulation is the infection of a single farm. Disease then develops until such time as clinical signs appear and infection is diagnosed. Meanwhile, disease spread between farms occurs and is modelled each day via a number of mechanisms including local spread and movement related spread. In the different processes of disease spread the geographic location of farms is taken into account via data on farm boundaries or farm point locations. Once diagnosis of the first infected farm is made, control measures are put in place that partly operate spatially as well (e.g. movement restrictions in radial zone around diagnosed farm). All processes regarding disease spread and control measures are modelled stochastically.

The output of the model includes, amongst others, the number of farms diagnosed, the dissemination rate, the number of animals slaughtered and the length of the epidemic.

The model kernel has been programmed in Borland C++. The user interface is made in Microsoft Access.

3.2 Results

A prototype version of the model was used to carry out a sensitivity and uncertainty analysis. Calculations were carried out for an area of 50*50 km, with the average Dutch farm density (2 per km^2). So in total almost 5000 farms (dairy, pig and mixed farms) are situated in the area. The first infected farm was located in the centre of the area. The control strategy applied represents the basic EU strategy. Disease spread parameters were based on the values defined for New Zealand (Sanson, 1993), except for those that are directly related to the structure/organisation of animal production (e.g. number of movements).

Table 1 gives some preliminary results of the sensitivity analysis in which disease spread parameters were modified. For each scenario 50 replications were carried out. Since the results are rather skewed, next to the mean number of outbreaks, parameters reflecting the spread in outbreaks are also presented. In the basic situation on average 29 outbreaks occur, but the standard deviation is large (30.9). In 50% of the cases the number of outbreaks is 20 or less, while no additional outbreaks occur in 6% of the cases and the 95% percentile is found at 103 outbreaks. In the basic situation, on average 1.9 movements were simulated off infected farms per day. A reduction of the number of movements of 25% results in a decrease of the mean number of outbreaks at a similar rate (from 28.7 to 21.6). An increase in number of movements of 25% results in a much larger increase in mean number of outbreaks (+77%). In case no movements would occur between farms, the extent of the out-

Table 1 Results regarding number of outbreaks for basic scenario and some alternatives

Scenario	Mean	S.D.	Median	Probability of 1 outbreak only	95% percentile
- Basic	28.7	30.9	20.0	0.06	102.5
- Movements +25%	51.0	63.5	29.0	0.08	156.1
- Movements -25%	21.6	26.1	10.5	0.12	91.7
- No movements	10.5	11.7	5.0	0.20	42.0
- Local spread +25%	44.4	46.2	29.5	0.04	158.1
- No local spread	7.8	10.4	4.0	0.24	32.0
- Prob of infection +25%	66.2	78.0	33.0	0.04	251.5
- Movements + 25% + Prob of infection +25%	149.0	138.9	119.5	0.06	433.5

breaks is more than halved. Moreover, in 20% of the cases the number of outbreaks is expected to be limited to one farm only. In case probabilities of local spread were set at zero, the mean number of outbreaks is reduced with more than 70%. When generating movements, a probability of infection is assigned to each movement of 0.5, 0.05 and 0.005 respectively for high (0.17 movements per day), medium (0.59) and low risk (1.14) movements. These probabilities of infection have been chosen arbitrarily. Increasing the probability of infection due to movements with 25% has a very large effect on the extent of the outbreak. Combining an increase in probability of infection with an increase in number of movements with 25% results in a further increase of the extent of the outbreak.

Objective of the model is to compare the consequences of different control strategies. This is illustrated here by presenting preliminary results of the uncertainty analysis regarding two control strategies. In the basic strategy, around each infected farm single radial zones are installed in which movements are restricted. In the alternative strategy, additionally, movements in the whole area of 50*50 km are restricted once the first case is diagnosed (referred to as restricted area (RA)). Figure 1 shows the cumulative frequency distribution of the number of outbreaks for both strategies (50 replications per strategy). Results are shown for two situations: basic and increased number of movements per day off infected farms. For the basic number of movements, in about 40% of the cases both strategies result in only a small number of outbreaks. In those cases, the strategy without RA will be cheaper, since there are fewer costs involved for farms that have been put on movement control. When the number of outbreaks runs more out of hand, the situation becomes even more worse in case no RA is installed. The reduction in costs of not having an RA will be overtaken by the increase in costs due to much more outbreaks, especially in the situation where the number of movements is increased.

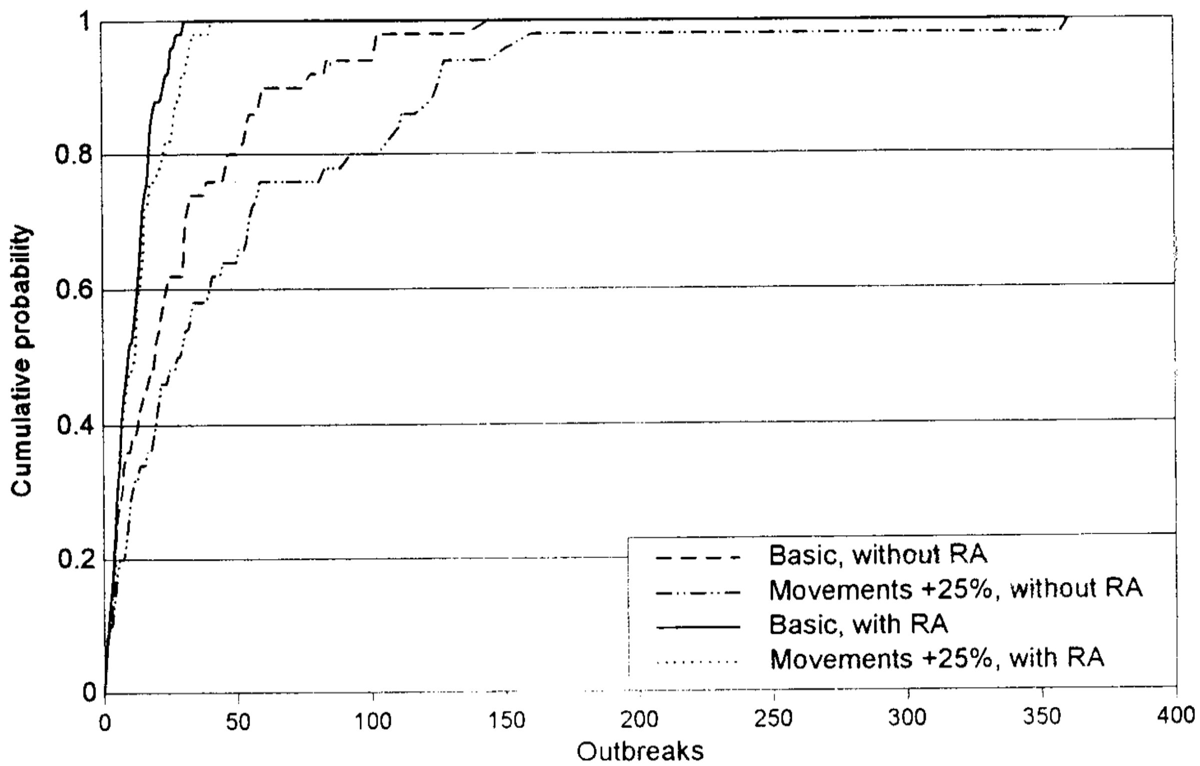

Fig. 1. Cumulative probability distribution of the number of outbreaks for scenarios that differ in number of movements and whether or not a restricted area is put in place.

4. DISCUSSION AND CONCLUSIONS

The results of the sensitivity analysis show that more effort is needed to obtain better information on the probability of local spread and the probability of infection due to movements of animals, people and vehicles. The probability of an individual farm becoming infected due to local spread off an infected farm is rather low (max. 0.05 per day) but has a large impact on the extent of the outbreak. These parameters, however, were estimated using data of a single epidemic only. The probability of infection due to movements will have to be more related to type of farm and number of animals involved.

To obtain the economic consequences of different control strategies, the results of the simulation of disease spread will be combined with a modified version of the model of Berentsen *et al.* (1990) to obtain direct costs of eradication and indirect costs due to export bans. In analyzing the results of control strategies, decision rules (stochastic efficiency criteria) will be applied to show the impact of various risk attitudes of decision makers in determining what control strategy to apply. The model can be used to test control strategies prior to implementation during an actual FMD outbreak, and can also be used as a research and training tool in periods without outbreaks. In that, it is absolutely essential to carry out an uncertainty analysis due to all the uncertainty in parameters and input variables regarding disease spread and effectivity of control measures.

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