Using epidemiological modelling to assist FMD preparedness in Australia

Graeme Garner explores how epidemiological modelling can assist in planning for and managing threats like foot-and-mouth disease

Abstract

Epidemiological modelling is a powerful tool to assist in preparedness for animal health emergencies. In Australia, the Australian Government Department of Agriculture, Fisheries and Forestry (DAFF) has developed a stochastic spatial simulation model that operates within a GIS framework. It simulates the spread of disease through space and time and has been designed to assist planning and training for FMD and other exotic diseases by enabling a range of outbreak scenarios to be studied and different control strategies to be evaluated under various conditions.

Introduction

Introduced animal diseases have the potential to cause significant impacts on animal health, public health, the economy and the environment. The greatest threat to Australia in terms of its economic impact is foot-and-mouth disease (FMD). A study by the Australian Productivity Commission (Productivity Commission 2002) concluded that an FMD outbreak would result in immediate closure of many of Australia's major export markets. The cumulative loss in export and domestic market revenues would be around $5.7 billion for a single point outbreak, rising to around $13 billion for an outbreak lasting 12 months.

A good understanding of the likely behaviour of FMD under Australian conditions is a necessary component of effective preparedness and response planning. Recent experience with FMD type O 'Pan Asia' strain outbreaks in previously disease-free countries like the Republic of South Korea, United Kingdom, France and the Netherlands have highlighted the importance of well-considered response strategies to manage an incursion.

Role of modelling

In the absence of contemporary experience with a disease like FMD in Australia, epidemiological modelling is one tool that can be used to study disease spread and management. The increasing recognition of local factors that affect spread and specific spatially-targeted strategies like emergency ring vaccination or contiguous slaughter, mean that models that take into account spatial relationships are becoming increasingly important.

Epidemiological modelling can be used for:

- risk assessments, ie to identify areas, sub-populations, production systems etc., that might be at greater risk from FMD;
- evaluating the effectiveness of various surveillance and control strategies;
- underpinning economic impact studies; and
- providing realistic scenarios for preparedness/training exercises.

The UK experience

Up until recently, models have rarely attracted much attention and had relatively little impact beyond the scientific realm (Pfeiffer 2004). In 2001, the United Kingdom experienced a severe epidemic of FMD. By the time it had been eradicated 31 weeks later more than 2000 farms had been infected and more than six million animals had been slaughtered—over four million for disease control purposes and over two million for welfare reasons. The direct cost to the public sector was estimated at over £3 billion and the cost to the private sector was estimated at over £5 billion (National Audit Office 2002).

This UK epidemic was unique, in that models were developed during the epidemic and, for the first time, used to directly control policy during an actual outbreak. The experience produced differing views as to the value of modelling, with some authors commenting on the important role that it played (e.g. Kao 2002) while others condemned it e.g. "*…surely the FMD experience should have made the modellers appreciate the limitations of their science and accept at least some responsibility for the misery and expense that their models initiated*" (Kitching 2004).

A recent comprehensive review of the use of models to inform disease control policy commissioned by the UK Department of Environment, Food and Rural Affairs (Taylor 2003) provides an informed and thoughtful assessment of the role of modelling in emergency disease management. It concludes that the most appropriate use of models is as tools in peacetime to aid retrospective analysis of real epidemics to gain insights. Hypothetical epidemics can then be modelled to better understand the relative merits of different strategies in different situations.

DAFF FMD model

DAFF has a long involvement in developing and using models. Previous work has looked at regional impacts of exotic diseases (Garner and Lack 1995a); evaluated control strategies (Garner and Lack 1995b, Garner et al. 1997); studied potential for wind-borne spread of FMD under Australian conditions (Cannon and Garner 1999); and provided hypothetical outbreak scenarios for studies on economic impact and zoning (OCVO 2002, Productivity Commission 2002).

The DAFF model is based on the work of Miller (1979) and James and Rossiter (1989) but has been considerably expanded in terms of scope and application from these early models. DAFF has now developed a sophisticated stochastic spatial simulation model that operates within a geographic information system (GIS) framework. It is designed to operate in a regional setting, using appropriate values for various parameters. A region is defined as an area that is reasonably homogenous in terms of climate and production systems.

Model operation

The DAFF FMD model is a stochastic simulation model. The individual unit of interest is a herd or farm. The model has a daily time step and is spatially explicit, ie it uses the location of all farms, either as points or polygons (land parcels). In the absence of 'real' data a method has been developed to 'synthesise' farm locations using agricultural census data and land use information.

The model simulates the spread of FMD through space and time. Disease spread is based on an effective contact rate (dissemination rate) that takes into account direct and indirect movements that could spread infection. There are separate modules to allow for wind-borne spread and spread through saleyards. Once the disease has been found, surveillance and control activities are imposed. Table 1 summarises key control options that are available in the model.

The user can define a scenario by setting where FMD is first introduced (single or multi-focal) and the delay from when disease is introduced until it is recognised. The user also sets resources constraints and how resources are partitioned between control activities. If resources are inadequate, a backlog of herds waiting to be visited, stamped out or vaccinated can build up. There is also the option of stopping the simulation at a given point in time and modifying the control strategy. Figure 1 shows the model set-up screen. Other parameters are stored in data files.

The model stores information on what happens on individual farms and provides summary outputs of events on a daily basis. It also includes a simple economic module that tracks control costs and compensation payments. Outputs are provided in the form of tables, graphs and maps. Figure 2 shows a sample output screen illustrating events during a simulation run for a small hypothetical outbreak in southern Queensland. Table 2 summarises a comparison between two possible

Table 1. Control measures available within DAFF FMD model

Control measure	Notes
Quarantine/movement restrictions	Changes in number and spatial pattern of contacts—in particular, reduction in longer-distance contacts.
Stamping out	Destruction of animals on infected premises (IPs).
Surveillance	1) Ad hoc reporting by farmers, veterinarians etc will generate suspect premises (SPs) subject to surveillance. 2) Local surveillance: patrol visits by surveillance teams—all farms within a given radius of IPs can be scheduled for surveillance. 3) Tracing: probabilities apply that farms linked to IPs will be identified by tracing procedures. These will be subject to surveillance visits.
Pre-emptive slaughter	Two options, separately or in combination: 1) Dangerous contact slaughter—destruction of animals on high risk farms Dangerouse Contact Premises or (DCPs) based on tracing. 2) Contiguous slaughter—destruction of animals on farms within a given distance of IPs. The option to slaughter SPs on suspicion is also available.
Vaccination	1) Emergency ('suppressive') ring vaccination. 2) Targeted vaccination—selective vaccination of 'high risk' premises.
Resources	Resource availability and increases in resources over time can be factored in.
Costs	Model tracks direct control program costs and compensation payments.

Table 2. Comparison of two control strategies with indicative costs, for a small hypothetical FMD outbreak in southern Queensland

Strategy 1: **local surveillance, stamping out of IPs and pre-emptive slaughter of DCPs.** ***Strategy 2:*** **stamping out of IPs and suppressive ring vaccination. One hundred model iterations have been used in each case.**

	Min. value	Max. value	Mean	Median
Strategy 1				
Epidemic duration (days)	35	90	57.7	59
IPs destocked	11	28	18.5	19
DCPs destocked	27	75	48.7	48
Total premises destocked	42	95	67.2	67
Premises vaccinated				
Control costs ($ '000)	3 428	9 261	5 701	5 618
Surveillance	603	2 531	1 005	983
Stamping out	2 825	6 730	4 696	4 635
Vaccination	-	-	-	-
Compensation ($'000)	13 152	41 154	23 936	23 250
Strategy 2				
Epidemic duration (days)	44	113	67.2	65
IPs destoked	18	41	30.1	31
DCPs destocked	-	-	-	-
Total premises destocked	18	41	30.1	31
Premises vaccinated	135	397	254.4	247
Control costs ($'000)	2 642	6 865	4 539	4 553
Surveillance	508	1 266	858	842
Stamping out	1 500	3 775	2 498	2 525
Vaccination	633	1824	1183	1186
Compensation ($'000)	8 313	57 994	30 124	31 535

Figure 1. Model set-up screen

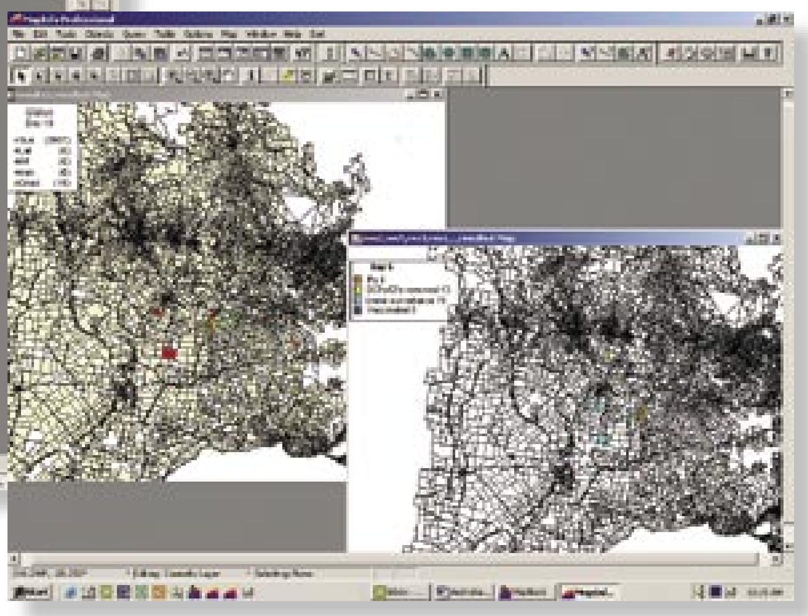

Figure 2. Sample output screens

control strategies. In this example, Strategy 1 results in more premises being stamped out and is marginally more expensive in terms of control costs, but on average reduces the size of an epidemic and results in lower compensation costs.

Discussion

Australia has developed a sophisticated disease model to assist in managing diseases like FMD. The approach has been designed to enable various outbreak scenarios to be studied. For example, one can take into account:

- different areas;
- various times until detection;
- different control strategies;
- availability of resources; and
- effectiveness of control measures.

The focus of the modelling on preparedness (ie pre-outbreak) rather than 'real time' tactical decision-making during an epidemic has been deliberate and is consistent with the findings from a recent review on the use of disease models in the UK (Taylor 2003). In developing the model, the philosophy has been to start simply and add complexity as and when it is needed. Hence, the model has evolved through a series of developmental stages.

The model is particularly useful for evaluating control strategies in the face of resource constraints. Advantages of the approach is that it captures key epidemiological features of an FMD outbreak, including chance elements. The model's logic is relatively straightforward; the complexity comes with estimating appropriate parameter values. The approach is also very flexible. Events can be thought of as being controlled by a series of 'rules'. The rules can be changed and control strategies can be readily modified. The model has been designed with high quality outputs, both visual and tabular, in mind (see Figure 2). This is especially useful for training purposes. It also keeps track of a lot of variables and extensive analyses on the effectiveness of different control options are possible.

However, the model is quite complex and requires good understanding of FMD epidemiology to set it up properly. A good knowledge of local conditions, movement patterns and animal management is also important to set parameter values realistically. As with any model the old adage 'garbage in, garbage out' applies. Unlike simpler mathematical models, the simulation modelling approach is computer intensive and long run times can be expected when the population is large and/or disease diagnosis is delayed. Finally, it needs to be appreciated that while the model is intended to be realistic, one is not dealing with reality—by definition models simplify the real world.

Future work is being planned through the new Australian Biosecurity Collaborative Research Centre for Emerging Diseases, which has identified *'developing new decision support tools and systems which exploit the potential of spatial analysis and computer modelling'* as an important component of its research program. This work is aimed at undertaking detailed studies of a series of potential outbreak scenarios that take into account a range of factors with a view to gaining insights into effective management of FMD under different situations. The intention is to also adapt the approach to other diseases of concern.

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