Combining the use of epidemiological and economic models as an aid in preparing contingency plans: a New Zealand case study

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Abstract:

A key decision when foot-and-mouth disease (FMD) is first confirmed in a country is whether to implement national livestock movement controls. Although the economic cost to New Zealand of a FMD outbreak has been reviewed, the cost of a livestock standstill is unknown, as is the impact of a standstill on the expected size or duration of a FMD epidemic.

A series of FMD epidemics within New Zealand was simulated using InterSpread Plus with New Zealand-specific parameters (the 'New Zealand Standard Model'). An economic model was developed using Microsoft Excel with an add-in Monte Carlo simulation. This model allows the input of a range of key variables to determine the costs of standstills of varying duration and geographic extent. Benefits were extrapolated from the epidemiological model in terms of standstill impact on epidemic size and duration.

Livestock standstills of varying geographic extent and duration did not significantly reduce the expected size or duration of an epidemic. Reasons for the apparent non-significant impact of a standstill may include the strict movement controls that will be immediately imposed in the infected zone (all districts within a 50 km radius of the index case), the high probability of disease detection and the low probability of long distance livestock movements. Standstill costs vary with outbreak location, time of year, commodity prices, standstill duration and the proportion of movement restrictions attributable to the controls rather than to the disease itself. However, even with the highest cost scenario the cost of a national standstill relative to the cost of a large or prolonged epidemic justify its application as a matter of policy. Further evaluation of the effects of defined standstill strategies for a wider range of outbreak scenarios and a review of epidemiological model inputs is in progress.

Introduction:

When foot-and-mouth disease (FMD) is confirmed in a country previously free of disease, one of the first decisions to be made is whether to implement a national livestock movement ban. Many countries, as a matter of policy, implement an immediate national livestock standstill as a standard control measure - for instance France (Le Menach et al., 2005) and Switzerland (Bachmann et al., 2005). The purpose of a standstill is twofold: firstly to slow down the movement and mixing of infected and susceptible livestock, and secondly to allow sufficient time to elapse to allow clinical signs to develop in infected stock, which increases the probability of disease detection (Anonymous 2003).

In the 2001 epidemic of FMD in the United Kingdom a 7 day national movement control was implemented 3 days after first confirmation of the disease (Matthews and Woolhouse 2005). It was estimated that by this time a total of 78 livestock premises were already infected and that there was widespread dissemination of infection via animal movements between farms and livestock markets (Matthews and Woolhouse 2005). Markets played a substantial role in disseminating disease in this epidemic (Matthews and Woolhouse 2005). In a submission to the House of Commons in 2002 it was concluded that if implemented immediately, a national livestock standstill would have resulted in an epidemic where the total number of infected premises was approximately one third to one half of the number actually recorded (Anderson 2002 The Royal Society of Edinburgh Inquiry (2002) recommended that a complete ban on the movement of susceptible animals be imposed immediately when FMD is confirmed, and that this ban may be relaxed in consultation with the relevant stakeholders, including rural businesses, once the source of the disease has been traced.

The cost of the 2001 epidemic in the UK has been estimated to be in the order of USD 5.7 billion, which reduced the gross domestic product (GDP) by less than 0.2% in 2001 (Thompson et al., 2002). New Zealand is unique among OECD countries in that 54% of its exports are in the form of agricultural products, and agriculture makes up 17% of GDP (Statistics New Zealand 2006). The most important consequence of an FMD outbreak in New Zealand would be trade losses due to exclusion from premium markets in FMD-free countries such as Japan, the European Union and the USA. New Zealand exports
80% – 90% of the food it produces and has a limited capacity to absorb reduced exports on the local market, unlike the UK where agricultural produce ineligible for export is able to be absorbed by the domestic market (Kitching et al., 2005). A FMD outbreak in New Zealand would reduce GDP by approximately 2.6% (Reserve Bank of New Zealand 2003). A rapid return to FMD free status and resumption of exports is therefore a major economic consideration for New Zealand, and this can only be achieved by reducing the size and duration of a FMD outbreak, should it ever occur.

New Zealand has in principle determined that a national livestock standstill will be implemented if FMD is confirmed in the country (Mackereth 2005). This will result in an immediate ban on the movement of susceptible species and germplasm throughout the country. In the infected zone(s) surrounding (the) infected place(s) more stringent controls will be enforced (Mackereth 2005). The national standstill would remain in place until epidemiological analysis became available that allowed the controlled area to be reduced to regional infected zone(s). Applications to move livestock would be considered on a case by case basis, and exemptions would be on a permit system. Section 162A of the Biosecurity Amendment Act (1997) allows compensation to be paid where verifiable losses or damages occur where powers under the Act are exercised for the purpose of managing or eradicating the disease.

Although many countries (including New Zealand) have reviewed the costs of FMD outbreaks and the costs associated with various control strategies, few (if any) have specifically examined the costs associated with livestock standstill bans. To address this issue for the New Zealand situation a project was initiated whereby the output from epidemiological modelling was to be used as input into economic modelling. A number of different scenarios using livestock standstills of different geographic extent and duration were compared. The project had two components: (1) to develop an epidemiological model looking at the impact of the various livestock standstills on the size and duration of a hypothetical FMD epidemic; and (2) to develop an economic model comparing the costs associated with each of the proposed livestock standstill policies.

Materials and methods:

The epidemiological model: A series of FMD epidemics within New Zealand were simulated using InterSpread Plus (Sanson 1993; Morris et al., 2001) with defined, New Zealand specific parameters (the so-called 'New Zealand Standard Model'; Stevenson et al., 2006; Sanson et al., 2006). The scenario was based on a single seeding of FMD virus into a piggery in the Manawatu, in the lower half of the North Island. Twelve scenarios were simulated involving: (1) livestock standstills of 0, 2, 3, and 14 days duration; and (2) standstills of varying geographic extent (lower North Island only, North Island only, and the whole of New Zealand).

Forty iterations of each scenario were run. Results were compared with a scenario where no movement controls were implemented, apart from movement controls within the infected zone(s).

The economic model: The project brief for the economic component of the study was to:

- review key economic impacts of livestock standstills of varying duration (2, 3, 7 and 14 days) and geographic extent, including Biosecurity Act provisions, as well as the environmental and social impacts of a standstill for FMD in New Zealand;
- design an appropriate analytical model for impact assessment;
- identify and collate current sources of economic information to be used in estimating impacts.

The challenge was to separate the costs of a standstill from the costs of the disease itself, and certain subjective assessments and assumptions had to be made to achieve this objective. The benefits of each intervention were not considered. The costs of managing the disease in the infected zone were specifically excluded, as were the costs of implementing the standstill (largely costs incurred by government and local agencies). A model was developed that looked at the cost of the standstill only – the benefits were then extrapolated from the epidemiological model, in terms of size of the epidemic and the duration of the epidemic (and thereby return to normal trading conditions).

The economic model was constructed in the Microsoft Excel spreadsheet package (Microsoft Corporation, Redmond, USA) implementing the add-in for Monte Carlo simulation, @RISK (Palisade Corporation, USA). The country was divided into 16 regional zones, corresponding to the regional zones used in the New Zealand Standard Model. The standstill pertains to movement of livestock and semen/germplasm only. The impact of the standstill was assessed for each major livestock sector (sheep, beef, deer, dairy, and pigs) as on-farm costs, beyond farm gate costs (including the primary sector service and processing industries), with macroeconomic flow-on effects considered. Seasonal factors were taken into account,
with the month in which the standstill occurred being a key input. The region(s) in which FMD was confirmed were excluded from the cost estimation from the time of confirmation, as these regions would be declared infected zones where movement controls would be implemented as part of the general epidemic control strategy. It was assumed that the duration of the standstill would be known in advance, as this would modify farmers’ behaviour and decisions. The model did not consider movements that would be exempted under permit, as the expected number of these cases was considered to be insignificant. The model determined the total cost of the standstill, and then allowed for the percentage attributable to the standstill (rather than to the disease itself) to be calculated.

Quantifiable on-farm costs included opportunity costs of feed, downgrading of carcasses associated with slaughter delays, costs associated with delays in artificial insemination, and the opportunity cost of management time associated with managing the standstill.

Results:

Epidemiological model: The median number of infected premises for the 0, 2, 3, and 14 day standstill scenarios was 33 (minimum 8, maximum 106), 31 (minimum 8, maximum 89), 31 (minimum 8, maximum 129), and 32 (minimum 8, maximum 76), respectively. A two way ANOVA showed that predicted numbers of infected premises did not differ among the four standstill periods (F<sub>3,54</sub> = 0.075; P = 0.97) or among the three standstill areas (F<sub>2,43</sub> = 0.090; P = 0.91).

Median epidemic duration for the 0, 2, 3, and 14 day standstill scenarios was 32 days (minimum 18 days, maximum 92 days), 32 days (minimum 18 days, maximum 82 days), 32 days (minimum 18 days, maximum 115 days), and 32 days (minimum 18 days, maximum 64 days), respectively. Predicted epidemic duration did not differ among the four standstill periods (F<sub>3,22</sub> = 0.061; P = 0.98) or among the three standstill areas (F<sub>2,82</sub> = 0.344; P = 0.71).

Economic model: Specific outcomes of the economic modelling were as follows:

- There was a significant seasonal variation in the economic impact on each industry sector. For dairy farms the largest impact occurred in the early spring (August), whereas for the sheep, beef and deer sector the largest impact occurred from mid summer to early autumn (January to April). The economic impact of a livestock standstill policy on the pig industry was constant throughout the year.
- Depending on the season in which the standstill occurred, cost incurred over a period was considerably longer than the length of the standstill itself (as a result of a ‘lag’ effect associated with clearing a backlog of livestock movements).
- The costs associated with preventing semen transfer between properties was significant in the dairy industry depending on the time of the year. While the same issue applied to the pig industry this was not a significant component of the total overall cost.
- The time associated with managing the implications of a standstill was significant, and varied depending on the time of year.
- The granting of movement permits has the potential to significantly reduce the costs of a standstill by allowing specific livestock movements to occur (e.g. movement of animals direct to slaughter).
- The variable having the greatest impact on the cost of a livestock standstill was the percentage of non-movement of stock attributable to the standstill, as opposed to the percentage attributable to the presence of the disease.
- There was a significant seasonal factor impacting on the total cost of a standstill, especially for the processing sector.
- The cost to the transport sector was proportional to the length of the standstill period.

Results obtained by varying the duration and month of the year of the standstill showed that the standstill would cost between NZD $16 and 44 million. Using the Reserve Bank of New Zealand’s General Equilibrium Forecasting and Policy System this cost does not have any discernible macro-economic impact, and therefore does not affect GDP.

Discussion:

Simulation modelling can be a useful exercise to gain insight into where standstill controls can contribute to the effective control of a FMD epidemic and can be used to quantify the magnitude of this effect. However, findings should always be interpreted in the context of the limitations of modelling, other control options, and the changing environment (Anonymous 2003). Models should be used to produce <i> a priori </i> supporting guidelines, rather than be used to make decisions under pressure during an epidemic (Taylor 2003). Modelling can play an important role in combing knowledge on disease epidemiology,
disease control, logistics of control and economic consequences, producing useful output for decision support (Taylor 2003).

Numerous models of FMD exist, which allow for evaluation of control measures, and the cost of an epidemic (Kostova-Vassilevska 2004). These models consist of a baseline epidemic model with superimposed models of control (Kostova-Vassilevska 2004). The reliability of evaluations and predictions depends on the reliability of the baseline epidemic model, and unrealistic representations can skew the evaluation of candidate control strategies (Kostova-Vassilevska 2004).

Work done in Switzerland by Bachmann et al. (2005), modelling the impact of various control measures on disease outcome using Interspread Plus, concluded that the lack of a nationwide ban on livestock movements resulted in an 8% increase in the total number of outbreaks, and a 4% increase in the duration of the epidemic compared with the baseline scenario with unlimited resources and a 72 hour livestock standstill. In this study the importance of animal movements in the spread of the disease was minor, with the proportion of outbreaks caused by movements < 10%, most likely due to the low frequency of animal movements off farms in this country (Bachmann et al., 2005). These findings agree with those of Mourits et al. (2002) who found that the implementation of a nationwide ban on livestock movements for 72 hours did not significantly reduce the size of the epidemics in densely populated livestock areas.

Varying the geographical extent and length of standstill period had little effect on the predicted number of infected premises and predicted epidemic duration in our study. This finding is thought to be largely due to parameter settings within the New Zealand standard model including: (1) the application of a large infected zone around the index case; (2) highly effective movement restrictions (> 98%) within the infected zone that persisted for the entire duration of the epidemic; (3) a high proportion of farms (> 95%) looking for disease, and promptly detecting it once control measures were applied; and (4) relatively small proportions of movements events occurring over a distance of greater than 80 km. While these parameters represent how an epidemic of FMD would evolve in New Zealand under 'ideal' conditions, we believe that there would be merit in evaluating the effect of the candidate standstill strategies under a broader range of ('less than ideal') scenarios – for example, where the effectiveness of movement restrictions and participation in surveillance for disease were reduced. Further movement studies and contact rate studies have been commissioned to review the validity of the current NZ Standard Model input parameters.

Decisions surrounding the implementing control strategies have three characteristics:

- **Uncertainty:** the spread of disease involves many biological and social processes subject to inherent randomness.
- **Irreversibility:** decisions (once carried out) cannot easily be reversed.
- **Leeway in timing:** in an epidemic the time allowed for decision making is limited. Any decision made in an uncertain environment therefore has an opportunity cost, in that it does not allow for the option of waiting for further information, and making better decisions at a later stage (Ge et al., 2005).

**Uncertainty:** At the time of first detection of FMD in New Zealand there will be a large degree of uncertainty as to: (1) the extent of the outbreak; disease (2) the origin of infection; (3) the number of animal movements that have occurred since the introduction of the disease; and (4) the strain of virus involved.

**Irreversibility:** Whatever decision is made about movement controls this has irreversible consequences. If a national livestock movement ban is not implemented immediately the potential advantages of such a ban will be lost. If a national livestock movement ban is implemented there will not be a significant reduction in costs if it is rescinded.

**Leeway in timing:** The UK reviews confirmed that a rapid response in declaring movement controls in a FMD outbreak is essential (Anderson 2002). During the 2001 FMD outbreak in the United Kingdom the Netherlands imposed progressive pre-emptive bans on the movement of susceptible livestock, and it was felt that these movement controls played a significant role in limiting the size of the outbreak in that country (Anderson 2002).

**Authors’ Conclusions:**
- In the event of confirmation of FMD in New Zealand it has to be decided in a very short time-frame (within 12 - 24 hours of confirmation) whether to impose a national livestock standstill, and this decision will need to be made before specific details about the outbreak are known if the full benefits of this strategy are to be achieved.
• Although the results obtained from modelling indicate that a national standstill does not significantly reduce the number of infected premises or epidemic duration, the relatively low cost of the strategy compared with the cost of a large, prolonged epidemic justify its application as a matter of policy.

Authors’ Recommendations:
• The standstill strategies described above require evaluation for a wider range of outbreak scenarios.
• Further contact rate and movement studies need to be undertaken, and the output used as revised inputs into the epidemiological model.

References:


