

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

**Multi-criteria decision analysis (MCDA) for control of transboundary  
livestock diseases using the example of the 2010/11 foot-and-mouth disease  
(FMD) outbreak in the Republic of Korea**

**A thesis presented in partial fulfilment of  
the requirements for the degree of  
Doctor of Philosophy  
in Veterinary Science**

**at Massey University Manawatū**

**EuTteum Kim**

**2015**

I hereby certify that the thesis has not been submitted for a higher degree at any University or Institution and work embodied in this thesis is my work unless noted otherwise in the acknowledgements.

---

EuTteum Kim

---

## Abstract

---

Decisions regarding transboundary livestock disease control strategies differ from personal decisions, such as buying groceries, in important ways: the stakes are high and the outcome of a decision will affect people in different fields. Decision making for transboundary livestock disease control strategies requires consideration of a number of factors including the epidemiology of the disease, economic cost of control, and environmental and social impact. For example, when applying pre-emptive slaughtering as a control measure for FMD, decision makers need to consider the epidemiologic effectiveness of the control measure, financial loss to farmers, the operational cost of slaughtering, negative impacts on the environment due to burning or burial of culled animals, and the public's concerns for the welfare of slaughtered animals. Therefore, it can be challenging for decision makers to choose the best control strategy among alternative strategies. The study presented in the thesis describes the application of multi-criteria decision analysis (MCDA) process as a decision support tool for decision making about transboundary livestock disease control strategies using an example of a simulated FMD outbreak.

The first research chapter (**Chapter 3**) investigates the preferences of chief veterinary officers (CVOs) for the criteria of FMD-control strategies in the Asia-Oceania region, which comprises countries free from or having experienced FMD. Criteria were grouped into epidemiologic, economic, and social-environmental. The CVOs in the Asia-Oceania region considered the epidemiologic criterion more important than the economic or the social-environmental criterion. The importance of the economic criterion differed with FMD status of a country: specifically, those countries considered free of FMD ranked the economic criterion as more important than those without. Among the criteria comprising the epidemiologic criterion, the most important was the size of the FMD-infected area, defined as the geographical size of FMD outbreak area. Within the economic criterion, the operational cost of the FMD-control strategy was considered the most important, and within the social-environmental criterion, the mental health of FMD-affected farmers was the most important criterion.

**Chapter 4** describes the construction of an epidemiologic model of the spread of the 2010/11 FMD outbreak in the city of Andong, Republic of Korea, to measure the epidemiologic effectiveness of FMD-control strategies. According to the simulation results, the model accurately represented the FMD outbreak in two ways: 1) the median number of simulated FMD-detected farms was the same as the number of detected farms during the actual FMD epidemic, and 2) the simulated epidemic curve was similar to the actual epidemic curve for the 2010/11 FMD epidemic. Thus, the constructed model could be used as a reference for evaluating the effectiveness of alternative FMD-control strategies.

The control strategy applied during the 2010/11 FMD epidemic consisted of a pre-emptive slaughter area with a radius of three kilometres, 100 day movement restriction, and vaccination of all FMD-susceptible animals in the country. This was used as a baseline strategy in the study. Alternative levels of these control measures for the FMD-control strategy were simulated to evaluate the effect of alternative strategies. Changes in control measures were: 1) pre-emptive slaughtering within a radius of 0.5, one, and five kilometres of FMD-infected farms; 2) movement restriction of 30 days and 60 days; 3) ring vaccination in a band three to five kilometres from FMD-infected farms. According to the simulation results, the five kilometres slaughtering strategy resulted in the fewest FMD-infected farms.

Cost-effectiveness (CE) analysis was applied to evaluate the economic effectiveness of FMD-control strategies using the results of epidemiologic simulation model (**Chapter 5**). This showed that ring vaccination in a band three to five kilometres from FMD-infected farms was the most cost efficient among alternative FMD-control strategies. The other FMD-control strategies, in decreasing order of economic efficiency, were five kilometre slaughtering, 30 day stop movement, and 60 day stop movement. The 0.5 kilometre and one kilometre slaughtering strategy were excluded in the analysis because these strategies did not control FMD spread during the simulations.

**Chapter 6** describes the MCDA process for choosing the optimal FMD-control strategy based on the results from **Chapters 3, 4** and **5**. The measurements of the criteria were merged with the weight of criteria to calculate the overall score of each FMD-control strategy. In the Asia-Oceania region, CVOs preferred ring vaccination over alternative FMD-control strategies, with 30 day stop movement being the least preferred of the FMD-control strategies.

The findings presented in each of these chapters have broadened our knowledge of the decision making process regarding FMD-control strategies. The processes were reliable, transparent, and reproducible and can be applied not only to FMD but also to other transboundary livestock diseases such as classical swine fever or highly pathogenic avian influenza.

---

## Acknowledgements

---

I offer my deep gratefulness to my supervisor team, Naomi Cogger, Tim Carpenter and Sarah Rosanovski for sharing their knowledge and expertise. Without their enthusiastic help, I would not have this thesis to present. Even though there were difficulties in analysing data and expressing the results scientifically, they always encouraged me. In particular, frequent meetings with my supervisors helped me to think about and resolve research problems. From each of my supervisors I learned not only how to think scientifically but much about the relationship between a student and a supervisor.

I sincerely thank the members of the Animal and Plant Quarantine Agency, Republic of Korea. Ha Chung Yoon, Soon Sik Yoon, Yeon Joo Kim, Woo Suk Jang, and Han Kim collected data and provided opportunities to experience government work, and in so doing, helped me understand the process of policy making for veterinary epidemiology.

I would like to express my appreciation to the EpiCentre staff, Bryan O’Leary, Cord Heuer, Christine Cunningham, and Simon Verschaffelt, for their support. I am also grateful to the EpiCentre students Jun Hee Han, Arata Hidano, Masako Wada, Nelly Marquetoux, and Juan Sanhueza for their friendship. The EpiCentre was a fantastic place to study epidemiology and widen my relationship with other epi-holic guys.

Finally, I want to express my love to my mother Sun Kyung Kim and my father In Ho Kim, who taught and supported me with endless love. My wonderful wife Ji Ye Heo is the great love of my life. I cannot imagine my life without you. My lovely daughter Ga On Kim entered and entirely changed my life; you are the amazing present I received from New Zealand.

Studying and living in New Zealand was an amazing experience — one I will never forget.

---

# Nomenclature

---

AUD	Australian Dollar
BCA	Benefit-Cost Analysis
BDI	Beck Depression Inventory
CSF	Classical Swine Fever
CVO	Chief Veterinary Officer
EU	European Union
FMD	Foot and Mouth Disease
FRF	French Franc
GBP	Great Britain Pound
HPAI	Highly Pathogenic Avian Influenza
KOSTAT	Statistics Korea
MCDA	Multi-Criteria Decision Analysis
MOSPA	Ministry of Security and Public Administration
OIE	The World Organization of Animal Health
USD	United States Dollar

---

## List of Figures

---

Figure 4.1. Timeline of the 2010/11 foot-and-mouth disease (FMD) epidemic in the city of Andong, Republic of Korea, and the commencement date of active surveillance, movement restriction, pre-emptive slaughtering, and vaccination (Day 1: 23 November, 2010)..... 80

Figure 4.2. Map of index farms for spatial and stochastic simulation models of foot-and-mouth disease (FMD) in the city of Andong, Republic of Korea. Inset: map of the Republic of Korea showing the location of the study area (FMD-infected farm on day 1 (red), day 2 (blue) and day 3 (black))..... 81

Figure 4.3. Cumulative number of foot-and-mouth disease (FMD) detected farms and simulated FMD-detected farms with 5th, 50th and 95th percentiles of baseline FMD-control strategy for controlling the 2010/11 FMD epidemic in the city of Andong, Republic of Korea (DTs: the number of FMD-detected farms)..... 82

Figure 4.4. Kernel-smoothed surface of the FMD-susceptible farms (left) and the simulated number of FMD-infected farms (right) per square kilometre in the city of Andong, Republic of Korea. Darker areas indicate higher density of farms; black points show the location of farms actually infected during the 2010-2011 FMD outbreak. .... 83

Figure 4.5. Map of the distribution of all FMD-susceptible farms located outside (blue dots) or inside (red dots) a three kilometre radius of FMD-infected farms (yellow circles) in the city of Andong, Republic of Korea. .... 84

Figure 5.1. Simulated cumulative distributions of alternative FMD-control strategies. The vertical solid line indicates the cost of the baseline FMD-control strategy (USD 99.7 million) and the horizontal solid line indicates a cumulative probability of 50%. Strategy 3: five kilometre slaughtering, strategy 5: 60 day stop movement, strategy 6: ring vaccination. The 0.5 and one kilometre



slaughtering strategies and 30 day stop movement strategy were excluded because they did not control FMD spread in the simulation..... 103

---

## List of Tables

---

Table 2.1. A numerical example showing the hypothetical measurement of duration of outbreak and z-score for foot-and-mouth disease (FMD) control strategies .....	30
Table 2.2. A numerical example showing the hypothetical calculation of overall scores for three foot-and-mouth disease (FMD) control strategies: depopulation, movement standstill, and vaccination. ...	34
Table 3.1. Foot-and-mouth disease (FMD) status of 21 participant countries in the study. ....	47
Table 3.2. The relative importance scores of criteria for a foot-and-mouth disease (FMD) control strategy according to the preferences of 21 chief veterinary officers (CVOs) or their representatives from the Asia-Oceania region. ....	48
Table 3.3. The relative importance scores of indicators in the epidemiologic criterion for a foot-and-mouth disease (FMD) control strategy according to the preferences of 21 chief veterinary officers (CVOs) or their representatives from the Asia-Oceania region. ....	49
Table 3.4. The relative importance scores of indicators in the economic criterion for a foot-and-mouth disease (FMD) control strategy according to the preferences of 21 chief veterinary officers (CVOs) or their representatives from the Asia-Oceania region. ....	50
Table 3.5. The relative importance scores of indicators in the social-environmental criterion for a foot-and-mouth disease (FMD) control strategy according to the preferences of 21 chief veterinary officers (CVOs) or their representatives from the Asia-Oceania region. ....	51
Table 4.1. Interval from exposure to incubation and infectious period and its cumulative probability as used in the foot-and-mouth disease (FMD) simulation model. ....	68
Table 4.2. Probability of a movement being within a distance band in the city of Andong, Republic of Korea. ....	69

Table 4.3. Daily probability that susceptible animals on a farm will be infected by local area spread, based on proximity to an infected farm in the city of Andong, Republic of Korea. ....	70
Table 4.4. Daily probability that susceptible animals on a farm will be infected by airborne spread based on proximity to an infected farm in the city of Andong, Republic of Korea. ....	71
Table 4.5. Details of baseline strategy and each alternative foot-and-mouth disease (FMD) control strategy. ....	72
Table 4.6. Parameters examined in sensitivity analysis. ....	73
Table 4.7. Simulated number of infected, detected, and depopulated farms and animals for a simulated baseline foot-and-mouth disease (FMD) control strategy to control the 2010/11 FMD epidemic in the city of Andong, Republic of Korea. ....	74
Table 4.8. Simulated foot-and-mouth disease (FMD) epidemic duration for differing radius of pre-emptive slaughtering area, duration of movement restriction, and application of vaccination for FMD-control strategies to control the 2010/11 FMD epidemic in the city of Andong, Republic of Korea. ...	75
Table 4.9. Simulated number of foot-and-mouth disease (FMD) infected farms and animals for differing pre-emptive slaughtering area, duration of movement restriction, and application of vaccination for FMD-control strategies to control the 2010/11 FMD epidemic in the city of Andong, Republic of Korea. ....	76
Table 4.10. Simulated number of depopulated farms and animals for differing pre-emptive slaughtering area, duration of movement restriction, and application of vaccination for FMD-control strategies to control the 2010/11 FMD epidemic in the city of Andong, Republic of Korea. ....	77
Table 4.11. Simulated number of vaccinated farms and animals for differing pre-emptive slaughtering area, duration of movement restriction, and application of vaccination for FMD-control strategies to control the 2010/11 FMD epidemic in the city of Andong, Republic of Korea. ....	78
Table 4.12. Simulated number of infected farms using the baseline foot-and-mouth disease (FMD) control strategy for different parameter values of the FMD-control strategy to control the 2010/11 FMD epidemic in the city of Andong, Republic of Korea. ....	79

Table 5.1. Details of baseline and alternative control strategies for foot-and-mouth disease (FMD) control in the city of Andong, Republic of Korea, 2010-2011. ....	94
Table 5.2. Estimated costs of compensation for cattle and pig farms depopulated due to foot-and-mouth disease (FMD) infection or pre-emptive slaughtering in the city of Andong, Republic of Korea, 2010-2011. ....	95
Table 5.3. Estimated management cost per disposal area* of slaughtered animals in the city of Andong, Republic of Korea. ....	96
Table 5.4. Estimated management cost for running one control office for 100 days to restrict the movement of animals and animal products during the foot-and-mouth disease (FMD) epidemic in the city of Andong, Republic of Korea, 2010-11.....	97
Table 5.5. Estimated cost for applying blanket vaccination to control foot-and-mouth disease (FMD) in the city of Andong, Republic of Korea, 2010-11.....	98
Table 5.6. Predicted foot-and-mouth disease (FMD) epidemic duration for different radius of pre-emptive slaughtering area, duration of movement restriction, and application of ring vaccination for FMD-control strategies to control the 2010/11 FMD outbreak in the city of Andong, Republic of Korea.....	99
Table 5.7. Simulated costs (USD million) for baseline and alternative foot-and-mouth disease (FMD) control strategies in the city of Andong, Republic of Korea.....	100
Table 5.8. Details for the median costs (USD million) for baseline and alternative foot-and-mouth disease (FMD) control strategies in the city of Andong, Republic of Korea, 2010-2011.....	101
Table 5.9. Sensitivity analysis of the detection probability of passive surveillance, the success probability of early movement restriction, and the number of farms that could be depopulated per day, expressed as expected median costs (USD million) for foot-and-mouth disease (FMD) control strategies in the city of Andong, Republic of Korea, 2010-11.....	102
Table 6.1. Details of baseline and alternative control strategies for foot-and-mouth disease (FMD) control strategies. ....	118
Table 6.2. The 21 participating countries from the Asia-Oceania region. ....	119

Table 6.3. The relative importance scores of criteria for a foot-and-mouth disease (FMD) control strategy according to the preferences of 21 chief veterinary officers (CVOs) or their representatives from the Asia-Oceania region. ....	120
Table 6.4. Standardized and weighted scores of foot-and-mouth disease (FMD) control strategies in the epidemiologic criterion. ....	121
Table 6.5. Standardized and weighted scores of foot-and-mouth disease (FMD) control strategies in the economic criterion.....	122
Table 6.6. Standardized and weighted scores of foot-and-mouth disease control strategies in the social-environmental criterion. ....	123
Table 6.7. Weighted overall scores and rankings of foot-and-mouth disease control strategies. ....	124
Table 6.8. Weighted overall scores and rankings of foot-and-mouth disease control strategies for the different simulation results. ....	125