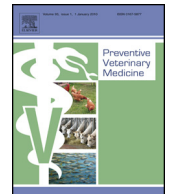




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Building a picture: Prioritisation of exotic diseases for the pig industry in Australia using multi-criteria decision analysis



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ABSTRACT

Diseases that are exotic to the pig industry in Australia were prioritised using a multi-criteria decision analysis framework that incorporated weights of importance for a range of criteria important to industry stakeholders. Measurements were collected for each disease for nine criteria that described potential disease impacts. A total score was calculated for each disease using a weighted sum value function that aggregated the nine disease criterion measurements and weights of importance for the criteria that were previously elicited from two groups of industry stakeholders. One stakeholder group placed most value on the impacts of disease on livestock, and one group placed more value on the zoonotic impacts of diseases. Prioritisation lists ordered by disease score were produced for both of these groups. Vesicular diseases were found to have the highest priority for the group valuing disease impacts on livestock, followed by acute forms of African and classical swine fever, then highly pathogenic porcine reproductive and respiratory syndrome. The group who valued zoonotic disease impacts prioritised rabies, followed by Japanese encephalitis, Eastern equine encephalitis and Nipah virus, interspersed with vesicular diseases. The multi-criteria framework used in this study systematically prioritised diseases using a multi-attribute theory based technique that provided transparency and repeatability in the process. Flexibility of the framework was demonstrated by aggregating the criterion weights from more than one stakeholder group with the disease measurements for the criteria. This technique allowed industry stakeholders to be active in resource allocation for their industry without the need to be disease experts. We believe it is the first prioritisation of livestock diseases using values provided by industry stakeholders. The prioritisation lists will be used by industry stakeholders to identify diseases for further risk analysis and disease spread modelling to understand biosecurity risks to this industry.

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1. Introduction

Freedom from many diseases affecting pig production in the rest of the world gives welfare, management and production advantages to the pig industry in Australia,

supporting its economic viability in a competitive market. However, the incursion of equine influenza into Australia in 2007 (Kirkland et al., 2011) highlighted that geographic isolation, trade restrictions and biosecurity do not guarantee protection from exotic disease incursions. Following the equine influenza incursion and the recommendations of the report “One health: a working partnership” (Beale et al., 2008), a project was initiated to investigate and prioritise exotic disease risks to the pig industry. The overall aim of the project is to enhance the industry’s preparedness

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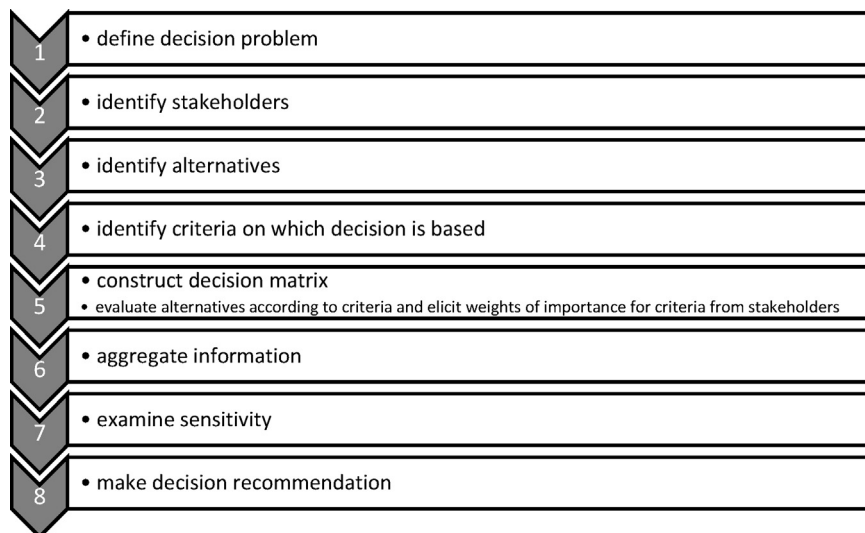


Fig. 1. Flowchart of steps for multi-criteria decision analysis (MCDA) using a multi-attribute decision making (MADM) structure.

and response to an incursion of the highest priority diseases in order to minimise impact on trade.

A variety of methods have been used to prioritise diseases. These include rapid risk analysis (McKenzie et al., 2007), qualitative decision trees (Palmer et al., 2005), consensus techniques (Weinberg et al., 1999) and semi-quantitative scoring techniques based on levels of severity of disease criteria that may or may not be weighted to contribute to disease importance (Carter, 1992; Rushdy and O'Mahony, 1998; Valenciano and Working Grp, 2001; Doherty, 2006; Krause and Prioritization Working Grp, 2008; Balabanova et al., 2011). All of these methods take into account the complex decision problem that is disease prioritisation; there is more than one criterion by which to rank the importance of a disease. However, the transparency of these prioritisations is affected by subjectivity when scoring diseases; particularly when using qualitative criteria that have been assigned arbitrary numerical levels of severity which are difficult to define.

More recently, multi-criteria decision analysis (MCDA) has been used for prioritisation of diseases or disease control options (Havelaar et al., 2010; Mourits et al., 2010; Humblet et al., 2012; Mintiens and Vose, 2012; Del Rio Vilas et al., 2013). MCDA is a group of established methodologies for decision analysis, used extensively in other disciplines such as information technology, engineering and environmental sciences (Bragge et al., 2010). The decision analysts in these projects aim to improve transparency and repeatability by using a structured MCDA approach.

The aim of this study was to combine disease information with pig producer values to prioritise exotic diseases for the pig industry in Australia, as a decision-aid to direct further research. To achieve this aim we used MCDA, applying a modified multi-attribute value theory (MAVT) based multi-attribute decision making (MADM) technique which used several approaches not widely used in previously in disease prioritisation. These novel approaches included using a set of quantifiable disease attributes as indicators of disease impact, deriving and validating weights of

importance from a stakeholder group (pig producers) not considered to be experts in diseases via an online survey (Brookes et al., in preparation), and presenting the results as series of prioritisation lists that build up impacts to aid communication with stakeholders. We evaluated this technique in the context of disease prioritisation in the Australian pig industry.

2. Materials and methods

2.1. Overview

MCDA is a family of decision-making methodologies that can be divided into two categories: multi-attribute decision making (MADM) and multi-objective decision making (MODM) methods (Triantaphyllou, 2000). MADM methods are designed to rank or group the best alternatives from a set of discrete choices by following a standard series of steps (Fig. 1), and can be used in disease prioritisation because there is choice over discrete alternatives (diseases or disease control methods). MADM methods can again be subdivided into elementary methods (pros and cons analysis, maximax and maximin methods, conjunctive and disjunctive methods, lexicographic methods), multi-attribute utility theory (MAUT) or multi-attribute value theory (MAVT) based methods, and outranking methods.

This study used a modified MAVT based method following the steps in Fig. 1. The decision problem was defined as ranking diseases exotic to the pig industry in Australia by potential impact and importance of those impacts to the stakeholders. The stakeholders were defined as pig producers in Australia. Diseases exotic to the pig industry in Australia were identified as the decision alternatives and criteria describing disease impacts were selected. Impacts included the potential effects of disease on the pig industry (described by on-farm effects of attack rate, length of clinical disease and case fatality rate in pigs, and industry wide effects of market loss and government cost sharing

Diseases	Criteria				
	C ₁	C ₂	C ₃	...	C _n
	w ₁	w ₂	w ₃	...	w _n
D ₁	a ₁₁	a ₁₂	a ₁₃	...	a _{1n}
D ₂	a ₂₁	a ₂₂	a ₂₃	...	a _{2n}
D ₃	a ₃₁	a ₃₂	a ₃₃	...	a _{3n}
...
D _m	a _{m1}	a _{m2}	a _{m3}	...	a _{mn}

D=1,...,m ; C=1,...,n w=1,...,n

Fig. 2. Multi-criteria decision analysis (MCDA) decision matrix used to compile information for disease prioritisation using a multi-attribute decision making (MADM) structure. D, disease identity; C, criterion; w, weight for criterion; a, measurement for each criterion for each disease.

in the case of a disease incursion), the ruminant industry (described by market loss to this industry), and human health (described by incidence, disability weight and case fatality rate in humans). Diseases alternatives were evaluated according to the criteria and stakeholder preference modelling was used to elicit weights of importance for the criteria (Brookes et al., in preparation). The decision matrix combining this information is shown in Fig. 2. The components were aggregated according to an additive value function based on multi-attribute value theory to produce a score range for each disease. The diseases were ordered according to the mean score to create prioritisation lists, and sensitivity of the scores to the criterion measurements was assessed. The lists were used as a decision aid to select diseases for further investigation of biosecurity requirements using risk analysis and disease spread modelling.

2.2. Disease identification

Exotic pathogens and disease syndromes were identified using the Generic Import Risk Analysis (IRA) for Pig Meat 2004 (Biosecurity Australia, 2004), and peer-reviewed literature. This was identified using a literature search of all citation databases in ISI Web of Knowledge using the following search terms: Title=(emerg*) AND Topic=(“pig” OR “porcine” OR “swine”), Refined by: Research Areas=(VETERINARY SCIENCES), Timespan = 1999–2012. A pathogen was included if:

- a. it can cause disease in either pigs, or ruminants or humans where the disease is transmitted either directly or indirectly from pigs,
- b. there is a potential vector in Australia for vector borne diseases, and
- c. the pathogen, or the disease syndrome it causes, is not currently recognised in Australia’s pig industry.

2.3. Criteria selection and disease evaluation

The research team selected the following nine criteria based on quantifiable disease attributes that would affect the impact of disease incursions across the pig industry (criteria i–v), the ruminant industry (criterion vi), and human health (criterion vii–ix). Each potential disease was evaluated according to the criteria, using information from industry and government department reports specific to

criteria, OIE publications (terrestrial animal health codes and manuals, technical disease cards) and peer-reviewed literature. If there were still information gaps, experts in specific diseases were consulted directly. Relevant peer-reviewed literature was identified using a literature search of all citation databases in ISI Web of Knowledge using the following search terms: Title=(“disease” OR “syndrome” OR “pathogen”) AND Title=(“review”), Timespan = All Years. The electronic search was supplemented with a hand-search of literature referenced by the identified reviews, the citation mapping tool on ISI Web of Science, and by consultation with experts who were identified through their published work. Worst case measurements that would be seen in the initial stages of a disease incursion in a naive population were used for each criterion. The criterion measurements for each disease were incorporated into the model as deterministic values. Uncertainty and variation in diseases (for example, attributes of differing strains) were reflected by creating more than one scenario for some diseases, so that variation in overall score for each disease was due solely to variation in stakeholder opinion.

2.3.1. Criteria

- i. Government contribution to industry to compensate for losses (0–100%): This was determined by the Emergency Animal Disease Response Agreement (EADRA) category (Animal Health Australia, 2001).
- ii. Pork market loss (0–100%): Information was taken from industry reports (Australian Pork Limited, 2010), government department reports (Australian Bureau of Statistics, 2010), OIE terrestrial animal health codes, and the Australian Veterinary Emergency Plan disease strategies and response policy briefs (Animal Health Australia, 2001).
- iii. Attack rate for pigs on a single farm (0–100%): A “standard” farrow to finish herd was used as the affected production unit, assumed to consist of 10% adult animals (70% pregnant) with the remainder of the population being young animals between 0 and 22 weeks old, with a weaning age of 4 weeks. Measurements reflected the percentage of pigs with clinical disease, rather than exposure measured by seroprevalence. For example, clinical signs for Japanese encephalitis in half of the pigs up to 6 weeks old (12% of the farm population) and abortion in 50% of pregnant adult sows (4%

- of the population) on a “standard” farm gave an overall attack rate of 16%.
- iv. Length of clinical disease in pigs (range 0–42 days).
 - v. Case fatality rate in pigs (0–100%).
 - vi. Ruminant market loss (0–100%): Information for this criterion was taken from industry reports ([Meat and Livestock Australia, 2009–10](#)) and the Australian Veterinary Emergency Plan disease strategies and response policy briefs ([Animal Health Australia, 2001](#)).
 - vii. Incidence in humans (0–100%): The number of the Australian population (size 20 million) that could be affected in the initial stages of a disease incursion was considered.
 - viii. Disability weight for humans (0–1): Information from the WHO Global Burden of Disease 2004 Update was used ([Mathers et al., 2006](#)). The measurement indicated the severity of the disease in humans.
 - ix. Case fatality rate in humans (0–100%).

2.4. Weights of importance for criteria

Weights of importance for the criteria were elicited in a separate stakeholder preference modelling study ([Brookes et al., in preparation](#)). The weight for each criterion indicates its importance in the context of this prioritisation to the stakeholders who took part in the study. A survey was designed and administered using SurveyMonkey.com, and distributed by Australian Pork Limited to members with registered email addresses. Participants completed the survey anonymously, and responses were collected between December 2011 and March 2012. Information was also collected about participant demographics and their sector of the pig industry.

Participants were asked to rank groups of test disease scenarios comprising the nine criteria described above. The test scenarios were designed to provide trade-offs between criteria, so that stakeholders could demonstrate preference through choice. They were also presented using terminology that could be understood by stakeholders without expert disease knowledge. Stakeholder groups with diverse preferences were differentiated and probabilistic inversion was used to infer distributions of weights of importance for the criteria from the scenario rankings for the stakeholder groups. [Neslo and Cooke \(2011\)](#) and [Kurowicka and Cooke \(2002\)](#) provide mathematical details of this technique. The validity of the weights was assessed using out-of-sample validation and the sensitivity of the predicted ranks to the elicited weights was assessed by prediction of ranks using equal weights.

2.5. Aggregation of criteria measurements and weights of importance

The distributions of weights of importance for the criteria were aggregated stochastically with the criterion measurements for each disease using Monte-Carlo simulation (software UNICORN v2.2 Pro ©2005 TU Delft & HKV consultants) according to an additive value function (linear weighted sum model; Eq. (1), where A_i is disease i , w_j is the weight of criterion j , and c_{ij} is the score of criterion j for disease i). This created a distribution of disease scores

reflecting differing stakeholder opinion according to the importance of the criteria and the criteria measurements for each disease.

$$A_i = \sum_{j=1}^9 w_j c_{ij} \quad (1)$$

The diseases were ordered by mean score and presented as centipede plots, built up in stages by adding groups of criteria to aid understanding of how the criteria affect disease order.

2.6. Sensitivity analysis of aggregated results to criterion measurements

Sensitivity of disease score to criterion measurements was assessed by aggregating the distributions of the weights with highest values of their ranges for each criterion in turn, whilst all other criteria measurements were set to zero.

3. Results

3.1. Disease identification

Diseases, pathogens or disease syndromes that were identified are shown in [Table 1](#); thirty were included for prioritisation, and sixteen were excluded from the study as they did not fulfil the inclusion requirements detailed in [Section 2.2](#).

3.2. Disease evaluation

[Table 2](#) shows diseases evaluated for pig farm impacts (criteria iii–v) only, according to the clinical signs expected in the first few days of an outbreak. [Table 3](#) shows diseases evaluated according to all pig industry and ruminant industry impacts (criteria i–vi), enabling stakeholders to evaluate the impact of diseases once government cost contributions, control measures and market restrictions are imposed. Control measures can alter the clinical picture on affected farms. An example is foot and mouth disease that has an attack rate of 100%, disease length of 1 day, and case fatality rate of 100% once control measures are instigated. [Table 4](#) shows diseases evaluated according to all the criteria. [Table 5](#) shows the zoonotic diseases evaluated for the human criteria (vii–ix) alone.

3.3. Stakeholder demographics and weights of importance for criteria

These results are summarised as stakeholder demographics and weights of importance for criteria are presented in ([Brookes et al., in preparation](#)). Briefly, fifty stakeholders responded to the survey (11.6%), divided into 38 stakeholders with a preference for the importance of livestock and industry impacts (the “livestock group”), and 12 with a preference for the importance of zoonotic impacts (“the zoonoses group”). The weights of importance for each group are shown in [Table 6](#).

Table 1

Diseases, disease syndromes and pathogens considered for prioritisation for the domestic pig industry in Australia.

Diseases/pathogens included in prioritisation ^a	Diseases/pathogens not included in prioritisation ^b
African swine fever	Clostridium difficile
Aujeszky's/Pseudorabies	Ebola Reston virus
Bovine tuberculosis (<i>Mycoplasma bovis</i>)	Echinococcus multilocularis
Classical swine fever	Getah virus
Cysticercosis (<i>Cysticercus cellulosae</i>)	MRSA (meticillin resistant <i>Staphylococcus aureus</i>)
Eastern Equine encephalitis	Norovirus
Eperythrozoon suis/ <i>Mycoplasma suis</i> 08/07	Porcine endogenous retroviruses
Epizootic transmissible gastroenteritis virus	Porcine kobovirus
Foot and mouth disease	Porcine bocavirus and other novel parvoviruses
Haemorrhagic septicaemia (<i>Pasteurella multocida</i> serotypes 6:B and 6:E)	Porcine lymphotropic herpesvirus
Japanese encephalitis virus	Porcine sapovirus
Menangle (<i>Porcine paramyxovirus</i>)	Porcine torovirus
Nipah virus	Rickettsia slovaca
Porcine brucellosis (<i>Brucella suis</i>)	SARS (severe acute respiratory syndrome)
Porcine epidemic diarrhoea (Asian strain)	West Nile fever
Porcine reproductive and respiratory syndrome: PRRS	Torque teno sus virus
PRRS (highly pathogenic strain, China 2006–7)	
Porcine respiratory coronavirus	
Porcine rubulavirus	
Post-weaning multisystemic wasting syndrome (PCV2AD)	
Rabies	
Salmonellosis	
Streptococcus suis new variants (e.g. SS2 ST7)	
Surra (<i>Trypanosoma evansi</i>)	
Swine vesicular disease	
Swine influenza	
Teschen disease/Porcine enterovirus encephalitis	
Trichinellosis (<i>Trichinella spiralis</i>)	
Vesicular exanthema	
Vesicular stomatitis	

^a Diseases, disease syndromes and pathogens identified as causing disease in either pigs, or ruminants or humans where the disease is transmitted either directly or indirectly from pigs, with a potential vector in Australia for vector borne diseases, and not currently recognised in Australia's domestic pig industry.

^b Diseases, disease syndromes and pathogens excluded due to insufficient information regarding their ability to cause disease in either pigs, or ruminants or humans where the disease is transmitted either directly or indirectly from pigs, whether there is a potential vector in Australia for vector borne diseases, or if it is currently recognised in Australia's domestic pig industry.

3.4. Results of aggregation of criteria measurements and weights of importance

The prioritisation lists are shown as centipede plots (Figs. 3–7). The diseases are ranked according to their final mean score after aggregation of weights of importance for the criteria with criteria measurements for each disease; the higher the score, the higher the priority of the disease. Standard deviation is also shown, and represents the variation in stakeholder opinion regarding the importance of the criteria included in the centipede plots for each disease. Standard deviation is specific to each disease score because the amount of variation in stakeholder opinion is different for each criterion (Table 6), and the values for each criterion vary between diseases.

The vesicular diseases – foot and mouth disease (FMD), swine vesicular disease and vesicular stomatitis – were the highest priority diseases for the stakeholders concerned most for livestock and industry impacts. FMD was the highest priority disease when only considering pig farm impacts with clinical signs reflecting the disease picture without imposed control measures and market loss (Fig. 3). When market losses and cost sharing agreements were considered, and pig farm impacts were altered to reflect the instigation of control policies such as on-farm slaughter, swine vesicular disease and vesicular stomatitis

(if undifferentiated from FMD) had highest priority to this group of stakeholders (Fig. 4). The priority of swine vesicular disease relative to FMD was increased further when potential zoonotic effects were added (Fig. 5). When differentiated from FMD, the priority of both swine vesicular disease and vesicular stomatitis reduced relative to FMD; this was the case regardless of the potential zoonotic impact of swine vesicular disease (Fig. 5). African swine fever and classical swine fever (acute form) were prioritised after the vesicular diseases, followed by the highly pathogenic form of porcine reproductive and respiratory disease (China 06–07 strain). Porcine reproductive and respiratory syndrome was also included in a less severe form and appeared as a much lower priority in all three livestock prioritisation lists. The weights of importance indicated that the zoonotic effects of diseases were not as important as the livestock and trade effects to this group of stakeholders (Brookes et al., in preparation) and this is reflected in the aggregated results for this group; diseases such as Nipah virus, Japanese encephalitis virus and rabies were not a high priority even once the zoonotic effects were added in the full impacts list.

The zoonotic disease prioritisation lists use the weights of importance from the stakeholders who had a preference for the importance of zoonotic diseases (Brookes et al., in preparation). When considering zoonotic effects alone

Table 2

Criterion measurements used for prioritisation of exotic diseases to the domestic pig industry in Australia by pig farm only effects (criteria considering pig and ruminant market loss, cost sharing, control measures and human disease are excluded).

Disease	ARpig ^a	Length ^b	CFRpig ^c
African swine fever, acute, lineage 1 (European)	95	5	90
African swine fever, acute, lineage 2 (Russian)	95	10	80
African swine fever, chronic	70	42	10
African swine fever, subacute	90	20	50
Aujeszky's/Pseudorabies	95	5	20
Bovine tuberculosis (<i>Mycoplasma bovis</i>)	1	2	2
Classical swine fever, acute	90	10	80
Classical swine fever, chronic	50	3	10
Cysticercosis (<i>Cysticercus cellulosae</i>)	0	0	0
Eastern Equine encephalitis	50	5	40
Eperythrozoon suis/ <i>Mycoplasma suis</i> 08/07	10	42	5
Epizootic transmissible gastroenteritis virus	100	7	35
Foot and mouth disease	100	42	30
Haemorrhagic septicaemia (<i>Pasteurella multocida</i> serotypes 6:B and 6:E)	15	1	70
Japanese encephalitis virus	16	5	80
Menangle (Porcine paramyxovirus)	50	2	10
Nipah virus	70	10	30
Porcine brucellosis (<i>Brucella suis</i>)	10	42	1
Porcine epidemic diarrhoea (Asian strain)	80	10	25
Porcine reproductive and respiratory syndrome	70	10	30
PRRS (highly pathogenic strain, China 2006–7)	95	7	50
Porcine respiratory coronavirus	0	0	0
Porcine rubulavirus	70	5	12
Post-weaning multisystemic wasting syndrome (PCV2AD)	10	30	80
Rabies	10	3	100
Salmonellosis	20	7	10
Streptococcus suis new variants, e.g. SS2 ST7	5	7	0
Surra (<i>Trypanosoma evansi</i>)	10	10	50
Swine vesicular disease	95	10	2
Swine influenza	90	5	3
Teschen disease/Porcine enterovirus encephalitis	75	5	75
Trichinellosis (<i>Trichinella spiralis</i>)	0	0	0
Vesicular exanthema	0	0	0
Vesicular stomatitis	50	10	2

^a ARpig, attack rate in pigs (%).

^b Length, length of clinical disease in pigs (days).

^c CFRpig, case fatality rate in pigs (%).

(criteria vii–ix), the highest priority diseases were rabies, Nipah virus, Eastern equine encephalitis then Japanese encephalitis (Fig. 6). When all the criteria were taken into consideration, these four diseases were interspersed with the vesicular diseases based on their zoonotic impact and high case fatality rate in pigs (Fig. 7). Rabies was still highest priority overall, and the relative order of the other three changed to Japanese encephalitis, Eastern equine encephalitis then Nipah virus. The swine fevers and porcine reproductive and respiratory syndrome were lower priority on this list than the lists for the stakeholder group concerned about livestock disease impacts. Attack rate in pigs had a negative mean weight for this group of stakeholders (Fig. 3) which caused diseases with high attack rate in pigs but low measurements for other criteria to appear lower on this list than expected – for example, swine vesicular disease when undifferentiated from FMD. The reasons and implications of this are discussed in Section 4.

3.5. Sensitivity analysis of aggregated results to criterion measurements

The sensitivity of disease score to individual criterion measurements for the stakeholders prioritising livestock

diseases showed that attack rate in pigs at its maximum value (100%) gave the largest score (Fig. 8). This demonstrates that changes to the value of this criterion give a proportionally larger change to the overall score for a disease, compared to equivalent changes in other criteria. The overall disease score is therefore most sensitive to changes in this criterion. Standard deviation in score was smallest for this criterion. A change in measurement of the incidence in humans made least difference to overall score, but standard deviation in score was large for this criterion. For the stakeholders prioritising zoonotic diseases, the overall score was most sensitive to disability (Fig. 9). The standard deviation in score was also the smallest for this criterion, increasing for case fatality rate in humans and incidence in humans.

4. Discussion

Prioritisations should be transparent, reproducible, flexible and represent the values of the stakeholders in order to be useful (Giesecke, 1999; Doherty, 2000; Krause and Prioritization Working Grp, 2008; Havelaar et al., 2010; Gilsdorf and Krause, 2011). MCDA aims to fulfil all these requirements. Using MCDA we combined and extended

Table 3

Criterion measurements used to prioritise exotic diseases to the domestic pig industry in Australia by pig and ruminant industry effects (criteria for human disease are excluded).

Disease	EADRA ^a	MLpig ^b	ARpig ^c	Length ^d	CFRpig ^e	MLRum ^f
African swine fever, controlled by stamping out	3	49	100	1	100	0
Aujeszky's/Pseudorabies	4	17	95	5	20	0
Bovine tuberculosis (<i>Mycoplasma bovis</i>)	4	10	1	2	2	0
Classical swine fever, acute, controlled by stamping out	3	49	100	1	100	0
Classical swine fever, chronic, modified stamping out	3	40	50	30	20	0
Cysticercosis (<i>Cysticercus cellulosae</i>)	0	0	0	0	0	0
Eastern Equine encephalitis	1	10	50	5	40	0
Eperythrozoon suis/ <i>Mycoplasma suis</i> 08/07	0	0	10	42	5	0
Epizootic transmissible gastroenteritis virus	4	10	100	7	35	0
Foot and mouth disease (FMD)	2	100	100	1	100	100
Haemorrhagic septicaemia (<i>Pasteurella multocida</i> serotypes 6:B and 6:E)	4	17	15	1	70	24
Japanese encephalitis virus	1	27	16	5	80	0
Menangle (Porcine paramyxovirus)	3	15	50	2	10	0
Nipah virus	1	27	70	10	30	0
Porcine brucellosis (<i>Brucella suis</i>)	0	10	10	42	1	0
Porcine epidemic diarrhoea (Asian strain)	0	0	80	10	25	0
Post-weaning multisystemic wasting syndrome (PCV2AD)	0	0	10	30	80	0
Porcine reproductive and respiratory syndrome (PRRS)	4	5	70	10	30	0
PRRS (highly pathogenic strain, China 2006–7)	4	10	95	7	50	0
Porcine respiratory coronavirus	0	0	0	0	0	0
Porcine rubulavirus	0	0	70	5	12	0
Rabies	1	10	10	3	100	6
Salmonellosis	0	10	20	7	10	0
<i>Streptococcus suis</i> new variants, e.g. SS2 ST7	0	10	5	7	0	0
Swine influenza	4	15	90	5	3	0
Swine vesicular disease, controlled by modified stamping out	3	25	95	10	2	0
Surra (<i>Trypanosoma evansi</i>)	4	5	10	10	50	10
Swine vesicular disease, controlled by stamping out	3	49	100	1	100	0
Swine vesicular disease, undifferentiated from FMD	3	100	100	1	100	100
Teschen disease/Porcine enterovirus encephalitis	4	17	75	5	75	0
Trichinellosis (<i>Trichinella spiralis</i>)	3	25	0	0	0	0
Vesicular stomatitis, controlled by stamping out	2	44	100	1	100	46
Vesicular stomatitis, undifferentiated from FMD	2	100	100	1	100	100
Vesicular exanthema virus	3	0	0	0	0	0

^a EADRA, Emergency Animal Disease Response Agreement category.

^b MLpig, market loss pork (%).

^c ARpig, attack rate in pigs (%).

^d Length, length of clinical disease in pigs (days).

^e CFRpig, case fatality rate in pigs (%).

^f MLRum, market loss ruminant industry (%).

techniques used in previous prioritisations, which provided advantages in all these respects.

Aggregation of criterion measurements and weights with a MAVT based function required quantitative criteria because arithmetic operations cannot legitimately be carried out on categorical data. This was advantageous in that scoring was straightforward (data was readily available for most diseases) and more importantly, the scores were objective, definitive measures and therefore transparent and reproducible. Previous prioritisation exercises have used levels of criteria to score diseases, either to allow use of categorical criteria such as potential threat, emerging potential and disease trend, or to reduce quantitative criteria to commensurable scales. In the case of categorical criteria, the decision-makers define an ordinal scale according to level of severity of the criterion. The levels are subjective and definitions can be open to interpretation, thus affecting both transparency and reproducibility. Disease prioritisations that have been repeated have addressed this problem by modifying and improving definition of criteria (Carter, 1992; Doherty, 2006) or seeking stakeholder input in designing future prioritisations

(Krause and Prioritization Working Grp, 2008; Gilsdorf and Krause, 2011). For both qualitative and quantitative criteria, using levels also inadvertently weights the criteria because the cut-offs between levels are arbitrary. For example, the study designers could choose to divide a criterion range (for example 0–100) into either 4 or 5 levels of equal size, giving the value 95 a score of 4 in one scheme, and 5 in the other. The study designers have therefore inadvertently added weight to some of the values in one scoring system compared to the other. As well as adding a subjective element that again reduces transparency and reproducibility, this could affect the order of ranking by influencing the overall disease score. In this study it was not necessary to reduce the criteria to commensurable scales. The MAVT based technique used here was modified to allow use of incommensurable scales, because the values elicited in the stakeholder preference modelling step were modelled within the MAVT function and are therefore implicitly related to the scales of criteria (Brookes et al., in preparation).

The MADM structure separated the objective criterion measurements from the subjective values of the

Table 4

Criterion measurements used to prioritise exotic diseases for the domestic pig industry in Australia by pig and ruminant industry effects and zoonotic disease effects.

Disease	EADRA ^a	MLpig ^b	ARpig ^c	Length ^d	CFRpig ^e	MLRum ^f	IncH ^g	DisWt ^h	CFRH ⁱ
African swine fever	3	49	100	1	100	0	0	0	0
Aujeszky's/Pseudorabies	4	17	95	5	20	0	0	0	0
Bovine tuberculosis (<i>Mycoplasma bovis</i>)	4	10	1	2	2	0	0.00000005	0.271	0.03
Classical swine fever, acute	3	49	100	1	100	0	0	0	0
Classical swine fever, chronic	3	10	50	30	20	0	0	0	0
Cysticercosis (<i>Cysticercus cellulosae</i>)	0	0	10	0	0	0	0.00000005	0.33	0
Eastern Equine encephalitis	1	10	50	5	40	0	0.00000005	0.616	0.6
Eperythrozoon suis/ <i>Mycoplasma suis</i> 08/07	0	0	10	42	5	0	0	0	0
Epizootic transmissible gastroenteritis virus	4	10	100	7	35	0	0	0	0
Foot and mouth disease	2	100	100	1	100	100	0	0	0
Haemorrhagic septicaemia (<i>Pasteurella multocida</i> serotypes 6:B and 6:E)	4	17	15	1	70	24	0	0	0
Japanese encephalitis virus	1	27	16	5	80	0	0.00000015	0.616	0.25
Menangle (Porcine paramyxovirus)	3	15	50	2	10	0	0.00000001	0.07	0
Nipah virus	1	27	70	10	30	0	0.00000005	0.616	0.6
Teschen disease/Porcine enterovirus encephalitis	4	17	75	5	75	0	0	0	0
Porcine brucellosis (<i>Brucella suis</i>)	0	10	10	42	1	0	0.00000025	0.279	0
Porcine epidemic diarrhoea (Asian strain)	0	0	80	10	25	0	0	0	0
Porcine reproductive and respiratory syndrome; PRRS	4	5	70	10	30	0	0	0	0
PRRS (highly pathogenic strain, China 2006–7)	4	10	95	7	95	0	0	0	0
Porcine respiratory coronavirus	0	0	0	0	0	0	0	0	0
Post weaning multisystemic wasting syndrome (PCV2AD)	0	0	10	30	80	0	0	0	0
Porcine rubulavirus	0	0	70	5	12	0	0	0	0
Rabies	1	10	10	3	100	6	0.00000005	1	1
Salmonellosis	0	10	20	7	10	0	0.00000005	0.105	0
<i>Streptococcus suis</i> new variants, e.g. SS2 ST7	0	10	5	7	0	0	0.00000005	0.616	0.15
Surra (<i>Trypanosoma evansi</i>)	4	5	10	10	50	10	0	0	0
Swine influenza	4	15	90	5	3	0	0.00000001	0.279	0
Swine vesicular disease, modified stamping out, mild zoonosis	3	35	95	10	2	0	0.00000001	0.07	0
Swine vesicular disease, modified stamping out, no zoonosis	3	25	95	10	2	0	0	0	0
Swine vesicular disease, undifferentiated from FMD, mild zoonosis	3	100	100	1	100	100	0.00000001	0.07	0
Swine vesicular disease, undifferentiated from FMD, no zoonosis	3	100	100	1	100	100	0	0	0
Swine vesicular disease, undifferentiated from FMD, serious zoonosis	3	100	100	1	100	100	0.00000001	0.616	0
Swine vesicular disease, not FMD, stamping out, mild zoonosis	3	49	100	1	100	0	0.00000001	0.07	0
Swine vesicular disease, not FMD, stamping out, no zoonosis	3	59	100	1	100	0	0	0	0
Swine vesicular disease, not FMD, stamping out, serious zoonosis	3	49	100	1	100	0	0.00000001	0.616	0
Trichinellosis (<i>Trichinella spiralis</i>)	3	25	0	0	0	0	0.00000001	0.35	0
Vesicular exanthema virus	3	0	0	0	0	0	0	0	0
Vesicular stomatitis (possibly FMD)	2	100	100	1	100	100	0.00000005	0.07	0
Vesicular stomatitis, differentiated from FMD, stamping out	2	44	100	1	100	46	0.00000005	0.07	0

^a EADRA, Emergency Animal Disease Response Agreement category.^b MLpig, market loss pork (%); ARpig, attack rate in pigs (%).^c ARpig, attack rate in pigs (%).^d Length, length of clinical disease in pigs (days).^e CFRpig, case fatality rate in pigs (%).^f MLRum, market loss ruminant industry (%).^g IncH, incidence in humans (%).^h DisWt, disability weight in humans (0–1).ⁱ CFRH, case fatality rate in humans (%).

Table 5
 Criterion measurements used to prioritise zoonotic exotic diseases for the domestic pig industry in Australia.

Disease	IncH ^a	DisWt ^b	CFRH ^c
Bovine Tuberculosis (<i>Mycoplasma bovis</i>)	0.00000005	0.271	3
Cysticercosis (<i>Cysticercus cellulosae</i>)	0.00000005	0.33	0
Equine encephalitis (eastern)	0.00000005	0.616	60
Japanese encephalitis virus	0.00000015	0.616	25
Menangle (Porcine paramyxovirus)	0.00000001	0.07	0
Nipah virus	0.00000005	0.616	60
Porcine brucellosis (<i>Brucella suis</i>)	0.00000025	0.279	0
Rabies	0.00000005	1	100
Salmonellosis	0.00000005	0.105	0
Swine influenza	0.00000001	0.279	0
Streptococcus suis new variants	0.00000005	0.616	15
Swine vesicular disease	0.00000001	0.616	0
Trichinellosis (<i>Trichinella spiralis</i>)	0.00000001	0.35	0
Vesicular stomatitis	0.00000005	0.07	0

^a IncH, disease incidence in humans (%).
^b DisWt, disability weight (0–1).
^c CFRH, case fatality rate in humans (%).

stakeholders (the weights of importance of the criteria), giving flexibility to the prioritisation; either of these sets of information can be re-evaluated without having to repeat the entire process. Multiple disease scenarios were tested without having to repeatedly consult stakeholders, as also demonstrated in other recent prioritisations (Havelaar et al., 2010; Humblet et al., 2012; Ng and Sargeant, 2012; Del Rio Vilas et al., 2013). In addition, this prioritisation demonstrated how the weights of importance from more than one stakeholder group could be aggregated to produce

prioritisation lists tailored to the values of different stakeholder groups without having to collect further disease information. This has wider implications than simply informing resource allocation for this stakeholder group. “Public perception” is often included as a criterion in disease prioritisations because it is recognised as an important driver of human and animal health policy. It comprises judgement of the impacts of a disease, including the mitigations, in a social and cultural context and therefore, defining and measuring public perception is a challenge.

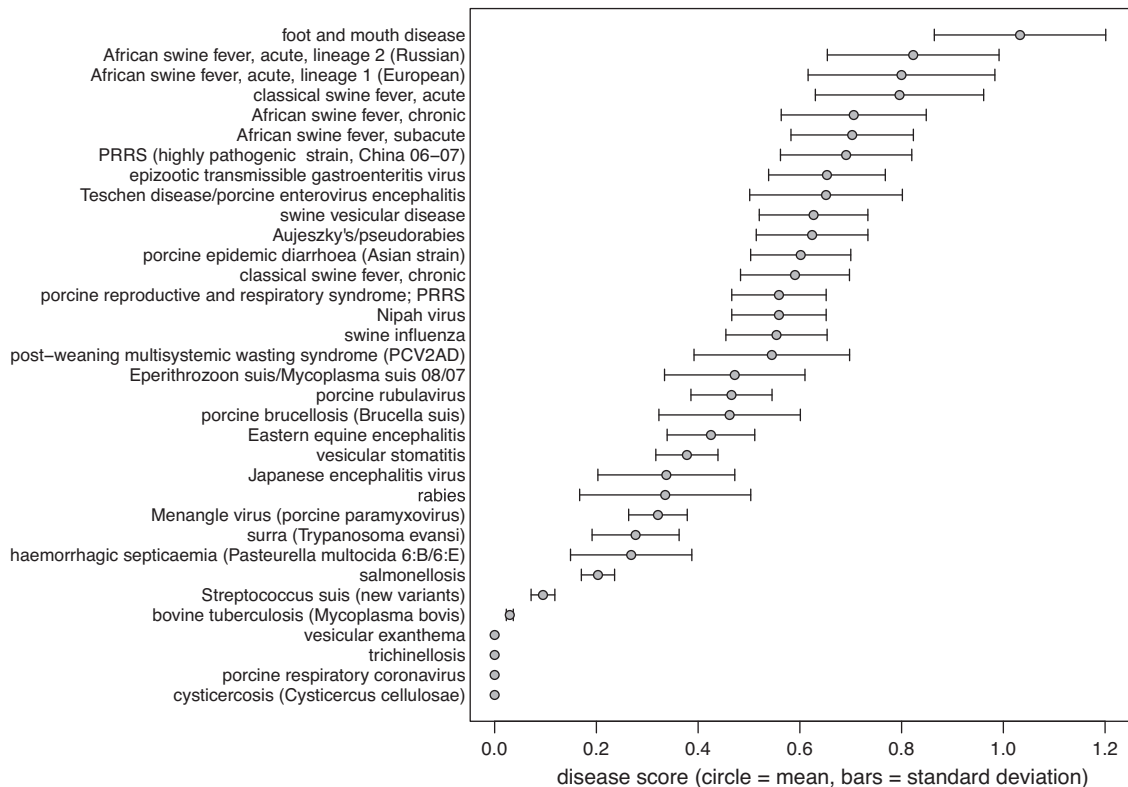


Fig. 3. Centipede plot showing disease scores for pig farm criteria only (iii–v) in order of priority (highest score at top) for the stakeholders concerned most for livestock and industry impacts. The mean score is represented as a circle, and the bars indicate standard deviation in stakeholder weights of importance.

Table 6

Weights of importance for criteria used for exotic disease prioritisation for the domestic pig industry in Australia (Brookes et al., in preparation).

Criteria	25th percentile		Median		Mean		75th percentile	
	L	Z	L	Z	L	Z	L	Z
i. Government cost share	0.04	-0.30	0.34	0.12	0.32	0.07	0.62	0.42
ii. Market loss pork	0.06	-0.20	0.44	0.22	0.39	0.15	0.76	0.54
iii. Attack rate pig	0.36	-0.54	0.64	-0.14	0.55	-0.10	0.84	0.32
iv. Length clinical disease pig	0.08	-0.46	0.50	0.06	0.40	0.03	0.78	0.52
v. Case fatality rate pig	-0.14	0.48	0.34	0.72	0.25	0.65	0.70	0.88
vi. Market loss ruminant	-0.08	-0.10	0.30	0.14	0.23	0.13	0.62	0.38
vii. Incidence human	0.08	-0.48	0.48	0.04	0.38	0.02	0.76	0.54
viii. Disability weight human	-0.48	0.30	0.06	0.62	0.02	0.52	0.50	0.84
xi. Case fatality rate human	-0.40	-0.06	0.06	0.44	0.04	0.30	0.50	0.72

L, weights for group of stakeholders with preference towards the importance of diseases affecting livestock.

Z, weights for group of stakeholders with preference towards the importance of zoonotic diseases.

Its definitions and levels have varied between prioritisations reflecting this difficulty (Carter, 1992; Rushdy and O'Mahony, 1998; Doherty, 2000; Del Rio Vilas et al., 2013). Prioritisations such as this can provide a model of public perception by using broad groups of stakeholders such as the general public to inform criterion weights, or smaller groups such as farmers and animal welfare organisations. This can be used to assist policy makers in understanding how people who are not health-experts value disease attributes and perceive the overall importance of different diseases.

The stakeholders in this prioritisation were divided over whether they placed more importance on the livestock and industry impacts of diseases, or the zoonotic impacts of diseases, and separate prioritisation lists were produced to reflect these diverse preferences. Vesicular diseases dominated the three prioritisation lists for the stakeholders who placed most importance on livestock and industry impacts of diseases. Building up the prioritisation in stages was an important communication tool because it allowed stakeholders to visualise how disease scores changed as different types of impacts were added. The highest weighted criteria

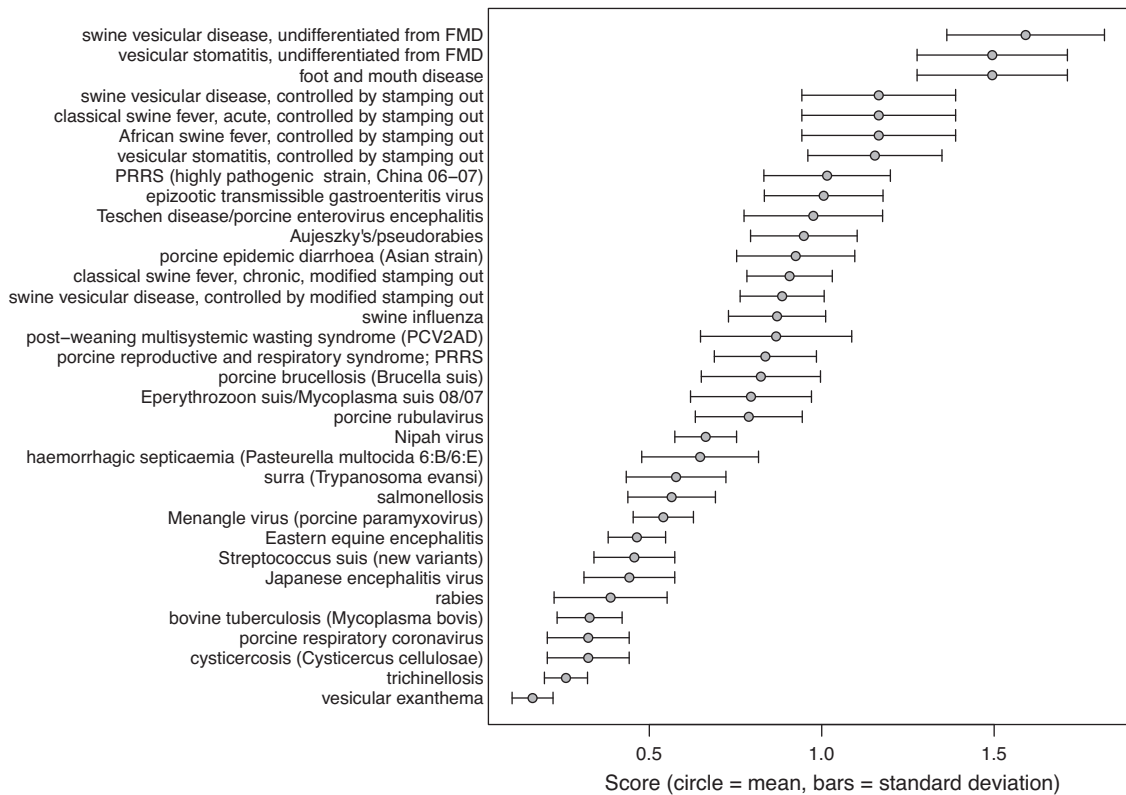


Fig. 4. Centipede plot showing disease scores for all pig industry and ruminant industry criteria (i–vi) in order of priority (highest score at top) for the stakeholders concerned most for livestock and industry impacts. The mean score is represented as a circle, and the bars indicate standard deviation in stakeholder weights of importance.

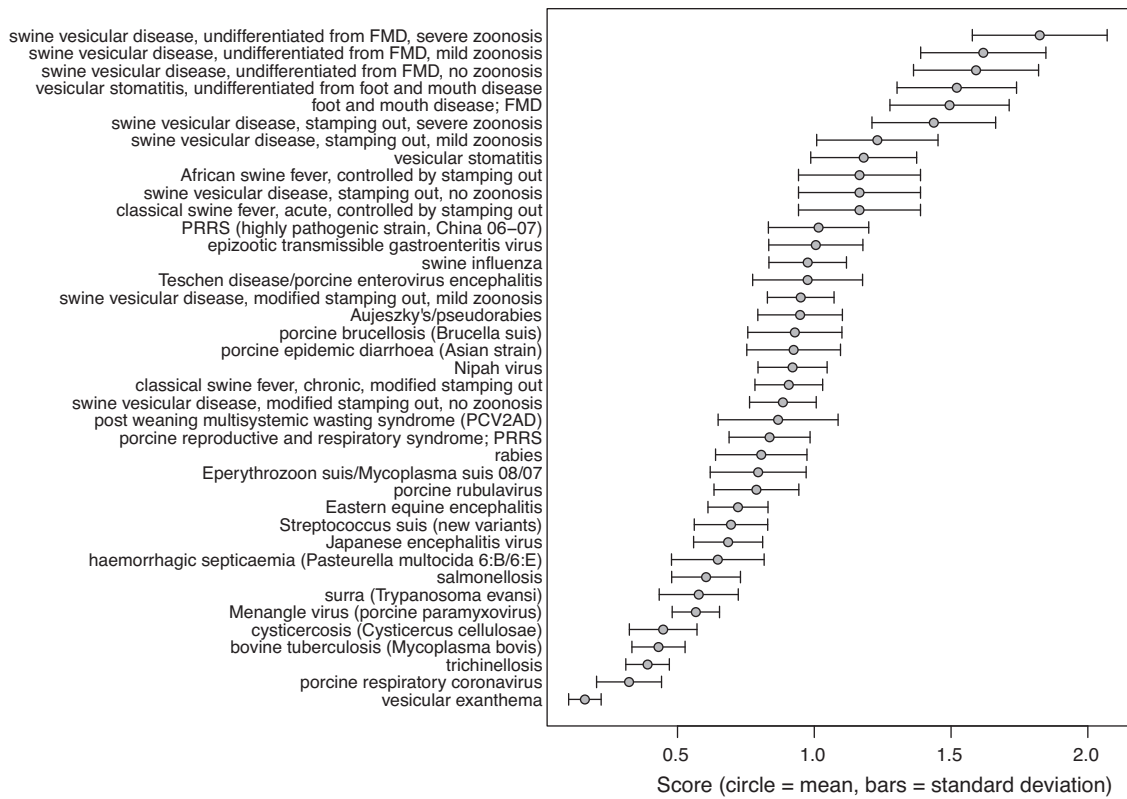


Fig. 5. Centipede plot showing disease scores for all criteria in order of priority (highest priority top) for the stakeholders concerned most for livestock and industry impacts. The mean score is represented as a circle, and the bars indicate standard deviation in stakeholder weights of importance.

for this group were attack rate and length of clinical disease in pigs (Brookes et al., in preparation). Therefore, foot and mouth disease (FMD) scored the highest in the first prioritisation list that considered pig farm criteria only, above acute forms of African swine fever and classical swine fever which had comparable attack rates in pigs, much higher case fatality rates but much lower lengths of clinical disease. Once the criteria for market loss for pigs and ruminants and the amount of cost sharing by the government were added to the next list, several scenarios for some diseases were included in order to account for variation

and uncertainty regarding disease measurements. When swine vesicular disease (SVD) and vesicular stomatitis (VS) were included as scenarios that were undifferentiated from FMD they ranked in first and second places respectively, due to lower cost-sharing by the government compared to FMD. Their priority diminished once differentiated from FMD, and again if modified stamping out was used rather than stamping out that does not allow process slaughtering. This showed that rapid differentiation from FMD and early detection of incursions of SVD and VS are both important factors in reducing the impact for this stakeholder group.

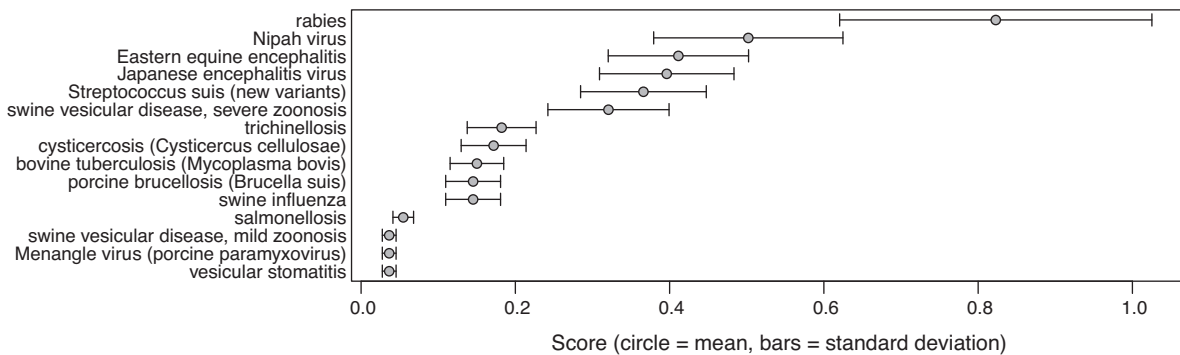


Fig. 6. Centipede plot showing scores for zoonotic diseases for human criteria (vii–ix) in order of priority (highest score to left at top) for the stakeholders who had a preference for the importance of zoonotic diseases. The mean score is represented as a circle, and the bars indicate standard deviation in stakeholder weights of importance.

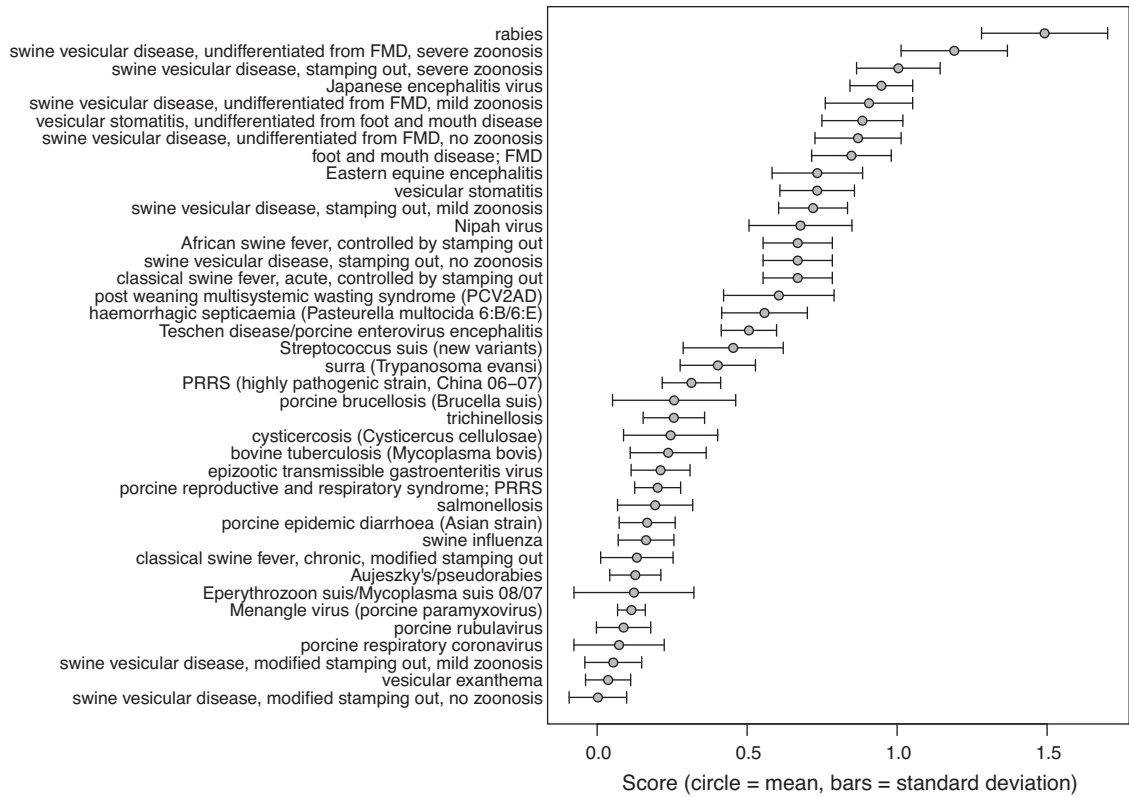


Fig. 7. Centipede plot showing scores for zoonotic diseases for all criteria in order of priority (highest priority top) for the stakeholders who had a preference for the importance of zoonotic diseases. The mean score is represented as a circle, and the bars indicate standard deviation in stakeholder weights of importance.

Two scenarios for porcine reproductive and respiratory syndrome (PRRS) were included, because different strains occur worldwide (Li et al., 2007). The China 06-07 strain, otherwise known as highly pathogenic PRRS, occurred as a severe outbreak of disease across China starting in 2006 (Tong et al., 2007). However, the pigs in China were co-infected with other pathogens (Zhou and Yang, 2010), making the severity of disease due to PRRS alone difficult to evaluate. Given the relentless spread of the highly pathogenic PRRS syndrome through south-eastern

Asia and Australia’s proximity to these outbreaks (An et al., 2011), this form was included in this study. It appeared high on the prioritisation list. The other form of PRRS included might be more typical of outbreaks in developed countries, such as the outbreak identified in Sweden in 2007 (Carlsson et al., 2009) which was detected by routine sero-surveillance and subsequently eradicated. This form of PRRS appeared much lower down the prioritisation list than highly pathogenic PRRS. The final list for this group of stakeholders included the criteria concerning the zoonotic

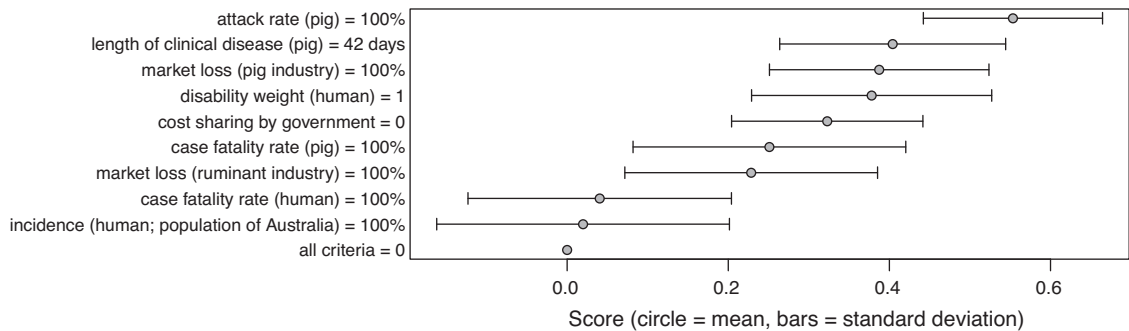


Fig. 8. Centipede plot showing sensitivity of disease score to criteria measurements for the stakeholders with a preference for the importance of the livestock impacts of disease. Each criterion is assessed by aggregating the distributions of the weights with highest values for each criterion in turn, whilst all other criteria measurements are zero. The mean score is represented as a circle; bars indicate standard deviation in stakeholder score.

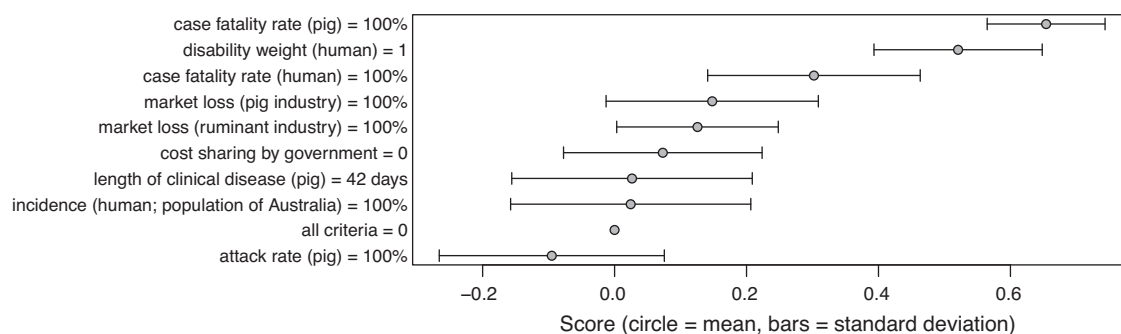


Fig. 9. Centipede plot showing sensitivity of disease score to measurements for human criteria, for the stakeholders with a preference for the importance of zoonotic impacts of disease. Each criterion is assessed by aggregating the distributions of the weights with highest values for each criterion in turn, whilst all other criteria measurements are zero. The mean score is represented as a circle; bars indicate standard deviation in stakeholder score.

effects of disease on human health. Overall, the disease order did not change markedly except for diseases with high disability weight such as rabies which increased in priority, as disability weight was the fourth highest weighted criterion for this group. We did not consider FMD as a zoonosis in this prioritisation because its transmission to humans is rare and accepted as causing very mild clinical signs (Prempeh et al., 2001). SVD is generally not considered to be a zoonosis at all. However, it was reported to cause disease in four laboratory workers and one person was hospitalised (Brown et al., 1976; Lin and Kitching, 2000). This potential level of severity of disease makes its zoonotic effects difficult to ignore, even if rare. However, if zoonotic transmission of the virus is not an important factor SVD also reduces in priority once differentiated from FMD.

The other group of stakeholders were more concerned about the impacts of zoonotic diseases: although case fatality rate in pigs was the highest weighted criterion for this group, case fatality rate and disability weight in humans were the next most important criteria. Consequently, zoonotic diseases scored much higher than in the livestock disease prioritisation lists. This stakeholder group was inconsistent in their preference rankings in the step to elicit criterion weights (Brookes et al., in preparation). It was recommended that these lists should be used to prioritise zoonotic diseases only, particularly as attack rate in pigs – their lowest weighted criterion – had a negative mean weight leading to unexpected final scores for diseases with high attack rate in pigs, but low criterion measurements otherwise. When zoonotic criteria were considered alone, rabies, Japanese encephalitis, Eastern equine encephalitis and Nipah virus were the highest priority diseases. These results are consistent with a recent prioritisation of zoonotic diseases using conjoint analysis of the preferences of a public stakeholder group in North America (Ng and Sargeant, 2012), and a prioritisation of zoonotic disease using MCDA and the values of disease experts (Havelaar et al., 2010). When all criteria and diseases are included rabies is still the highest priority disease, followed by SVD as a zoonosis and Japanese encephalitis. FMD and SVD undifferentiated from FMD are still high priority due to their high case fatality rates when stamping out is used to control disease on farms.

Lack of inclusion of risk, direct economic analysis and control methods such as vaccination and treatment could be seen as limitations of this prioritisation. Risk is dependent on many environmental and host factors as well as disease characteristics. Whilst more than one scenario has been included to account for variations and uncertainty in disease characteristics, including multiple scenarios or probability distributions to account for variation and uncertainty in host and environmental characteristics is beyond the scope of disease prioritisation and this is better investigated via risk analysis. We considered the stakeholders to be experts in pig farming, and therefore able to interpret disease information in terms of economic impact on their farms and to their industry. More detailed economic analysis could be carried out subsequently on selected diseases. Control methods such as treatment or vaccination are either preventive or instigated secondary to a disease incursion, and can also be considered subsequently. Ultimately, MCDA in disease prioritisation is an aid to decision-making, not a substitute for making decisions. It provides a baseline of information about disease impacts according to stakeholder opinion. Selection of diseases for resource allocation for either surveillance and prevention or control will be influenced by other factors such as risk of disease entry (Cox, 2009), once the diseases have been ordered.

Limitations concerning the number of criteria used to describe impact, the number of stakeholders participating in the study and the demographics of the stakeholder group are discussed elsewhere (Brookes et al., in preparation). Another limitation of this prioritisation is exclusion of diseases due to insufficient information. It is possible that they could be of high priority if they could be included. A procedure involving the use of algorithms such as those described and used by the Human Animal Infections Risks and Surveillance Group (Palmer et al., 2005; Morgan et al., 2009), could be modified and used to assess information gaps and potential threats from these diseases.

5. Conclusion

This paper presents the second part of a study to prioritise exotic diseases for the pig industry in Australia using MCDA, in which disease information was combined

with stakeholder values to produce disease lists ordered by scale of potential impacts and importance of those impacts. Whilst MCDA has been used in previous disease prioritisations, this is the first prioritisation of diseases of livestock using MCDA that reflects the values of a specific group of public stakeholders who are not considered disease experts. Although the aim of decision making is to usually combine the opinions of all stakeholders, producing two sets of prioritisation lists at the aggregation step of this MCDA allowed better representation of the values of the stakeholder group rather than producing an “average” list that suited nobody. Overall, quantitative criterion measurements through the use of MAVT and separation of objective criterion measurements from subjective weights of importance through the MADM structure provided transparency, reproducibility and flexibility to the prioritisation, and provided stakeholders with a decision-aid based on their own values. It subsequently allowed the stakeholders to make an informed decision about which diseases should be prioritised for further investigation of biosecurity requirements using risk analysis and disease spread modelling.

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