RESEARCH REPORT
SWINE HEALTH

Title: Animal welfare implications resulting from movement restriction for foreign animal disease outbreak management in the pork industry - **NPB #13-153**

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Industry Summary: Trends in the U.S. swine industry show that over the years, there has been an increase in improved producer efficacy and the appearance of fewer but larger pig farms. These changes are reflected in larger litter sizes, increased numbers of market pigs and pork production per breeding animal, and slaughter weights. These modern intensive pork-production systems, however, may pose new challenges in disease-outbreak controls. When a foreign animal disease (such as foot-and-mouth disease or classical swine fever) emerges, countermeasures must be implemented immediately. One of the control strategies is movement restriction, in which the movement of live pigs, pork products, vehicles and people is halted. Movement restriction is an essential measure to stop diseases from spreading and preventing a lengthy epidemic. However, discontinuation of these routine movements can quickly lead to adverse animal-welfare conditions, such as overcrowding among finishing pigs and feed interruptions. In fact, historical foreign animal disease outbreaks have shown that the number of healthy pigs euthanized due to adverse animal-welfare conditions often exceeded the number of pigs euthanized due to infections. For example, during the 1997–1998 classical swine fever outbreaks in Europe, the pigs that were euthanized due to adverse animal-welfare conditions comprised 62%–87% of all pigs euthanized, and their associated costs comprised more than 50% of the total direct costs of the overall outbreak-control initiative (Edwards et al., 2000; Terpstra and de Smit, 2000).

Despite its importance, very few studies have attempted to quantify the impacts of movement restrictions on the well-being of pigs during a foreign animal disease outbreak (Bargen and Whiting, 2002). Therefore, our team initiated a series of studies to quantitatively assess the impacts of movement restrictions on associated animal welfare outcomes. In this paper, we reported one of the studies with the specific objectives of (a) establishing a conceptual framework for the development of novel risk assessment models; (b) collecting available data to build model algorithms; and (c) using these models to evaluate different movement-control policies for foreign animal disease-outbreak management. Our goal was to compile and use routinely collected surveillance data on the U.S. swine industry to develop models that can promptly generate important outbreak-related information (for example, how long an outbreak might last and how many swine premises might be affected). The use of available data allows different users to easily update the models with the latest information (for example, where an outbreak starts and the ages of pigs on a farm when an

outbreak starts) or to adapt the models to fit specific needs. Prompt and accurate outbreak-related information is essential for pork producers to make evidence-based decisions so the potential losses due to an outbreak may be reduced.

In this study, we used classical swine fever as a disease-outbreak model and the data on the swine industry in Indiana to develop the models. We conducted a focus group discussion among experts in pork production, epidemiology, and animal welfare, and swine veterinarians to establish a conceptual framework. We decided to focus on the two adverse animal-welfare consequences of movement restriction—namely, overcrowding and feed interruption. In addition, we decided to evaluate two movement-control policies for disease outbreak management: complete movement restriction and controlled movement. On-farm euthanasia was the only mitigation option that was used to alleviate adverse animal-welfare conditions under the complete movement restriction policy, whereas under the controlled movement policy, market-age pigs were allowed to be moved to slaughter plants after a pre-movement inspection. We used this conceptual framework and the collected data to build the models.

Our study revealed that overcrowding and feed interruption could occur within swine premises under movement restrictions very quickly (< 2 weeks) after an outbreak started. The adverse animal-welfare conditions, on average, were predicted to occur faster in nursery operations than in finisher operations. Our models also supported the implementation of the controlled movement of market-age pigs to slaughter plants as a low-risk alternative to complete movement restriction, in which on-farm euthanasia would be used as the only mitigation strategy for alleviating adverse animal-welfare conditions. Allowing healthy pigs on the premises under movement restrictions to be shipped to slaughter plants may greatly reduce economic losses; our models estimated that this controlled movement strategy could be used to alleviate adverse animal-welfare conditions on about 67% of the premises that encountered problems.

Keywords: classical swine fever, disease outbreak control, movement restriction, overcrowding, animal well-being

Scientific Abstract: Movement restriction is considered an essential countermeasure to block disease spread during a foreign animal disease (FAD) outbreak. However, historical FAD outbreaks have shown that during outbreaks, movement restriction has great impacts on the well-being of pigs. In this study, we used classical swine fever (CSF) and the data of the swine industry in Indiana to develop different stochastic risk models to evaluate two movement-control policies—namely, complete movement restriction and controlled movement—with an emphasis on the specific adverse impacts on the well-being of pigs. We developed the first model to estimate the amount of time that elapsed before overcrowding or feed interruption emerged on swine premises under movement restriction during a CSF outbreak in Indiana. We developed the second model to assess the risk of secondary outbreaks that could occur due to the controlled movements of pigs from movement restriction zones to slaughter plants. We modeled nursery (19 to 65 days of age) and finisher (40 to 165 days of age) pork-production operations separately. We defined overcrowding as a condition in which the total weight of pigs on premises exceeds 100−115% of the maximum capacity of that premises, which was determined by computing the total weight of all of the pigs at the harvest/transition age. We developed model algorithms to estimate the age-specific weights of the pigs on premises and to compare the daily total weights of the pigs with the threshold weight that defined overcrowding. We implemented this procedure in order to flag the time at which the total weight exceeded the threshold (i.e., when overcrowding occurred). We developed another set of algorithms to model a swine producer's decision to discontinue feed supply. We incorporated the assumptions that (a) a longer estimated epidemic duration, (b) a longer time interval between the age of pigs at the onset of the outbreak and the harvest/transition age, or (c) a longer progression of an on-going outbreak would increase the probability of a producer discontinuing the feed supply.

We assumed that adverse animal-welfare conditions would emerge shortly after an interruption of feed supply. Simulations were run with 100,000 iterations each for a 365-day period. The median (5th and 95th percentiles) time at which either overcrowding or feed interruption emerged was 18 days (4, 40) in nursery operations and 57 days (4, 130) in finisher operations. These estimates may help decision makers plan for effective management of a CSF outbreak and swine producers to minimize economic losses and make informed decisions on the continuity of their businesses.

Using the swine premises statistics in Indiana, our risk assessment model estimated that approximately 9% to 23% of the swine premises in Indiana would encounter adverse animal-welfare conditions due to movement restrictions. Under complete movement restriction, all pigs on premises that encountered adverse animal-welfare conditions would be euthanized on farm to alleviate the conditions. Under controlled movement, the model estimated that on-farm euthanasia needed to be performed on only approximately 33% of the swine premises that encountered overcrowding or feed interruption. We estimated that movement of pigs to slaughter plants could be initiated to alleviate the adverse animal-welfare conditions on approximately 67% of premises. The risk of secondary outbreaks due to movement of pigs from movement restriction zones to slaughter plants was low, and we determined that testing a sample of seven pigs for CSF from each shipment would be sufficient to detect infection in the shipment.

In summary, our study's risk assessment models determined the early onset of adverse animal-welfare conditions within swine premises that were under movement restriction. Our models supported the controlled movement of market-age pigs to slaughter plants as a low-risk alternative to complete movement restriction wherein on-farm euthanasia is the only mitigation strategy for alleviating adverse animal-welfare conditions. Movement of pigs to slaughter plants could be used to mitigate approximately 67% of the adverse animal-welfare conditions due to movement restrictions.

Introduction: Movement restriction is an essential control strategy for FAD outbreak control. The current USDA FAD management manual states that movement restriction is to be imposed within 7-km of the perimeter of an infected zone, in which movement of pigs, vehicles and personnel is restricted.

Extended periods of movement restriction could lead to the emergence of animal-welfare problems (e.g., overcrowding and feed interruptions) on swine premises. The modern intensive swine operations in the United States often utilize the maximum available space allowed for raising pigs. Overcrowding might emerge very quickly on premises after the imposition of movement restriction. Moreover, the average daily weight gain and litter sizes of pigs have increased, and mortality has gone down among U.S. pork productions (Stalder, 2012, 2013, 2014). Improved producer efficacy may accelerate the occurrence of overcrowding. Restrictions on the movement of vehicles during an outbreak can interrupt the feed supply on swine premises (Crispin et al., 2002; Galli, 2011). Furthermore, pork producers may decide to discontinue business during a CSF outbreak in order to reduce economic losses. This decision would also result in feed interruptions and on-farm euthanasia of pigs as the required solution to alleviate animal-welfare consequences.

Seven million healthy pigs were euthanized to alleviate the animal-welfare consequences of movement restriction in the 1997-1998 CSF outbreaks in the Netherlands (Elbers et al., 1999; Scudamore and Harris, 2002). A larger number of pigs were culled due to animal-welfare conditions compared with infections, which incurred more than 50% of the total cost attributed to managing animal-welfare conditions during the outbreak ((Elbers et al., 1999; Pluimers et al., 1999; Edwards et al., 2000); Saatkamp et al., 2000; De Vos et al., 2005). Euthanasia of a large number of healthy pigs can lead to great emotional and economic burdens on both pork producers and outbreak-management authorities. In addition, these efforts may compete for the shared resources for other concurrent outbreak-control activities (such as pre-emptive culling and carcass transport and

disposal), which may hamper the progress of outbreak management and result in a prolonged epidemic (Elbers et al., 1999). In the context of the U.S. swine industry, a large number of swine premises may be placed under movement restriction during a CSF outbreak; this indicates that there is a demand for enormous resources for the enforcement and management of subsequent animal-welfare conditions (East et al., 2014). Therefore, it is crucial to develop a framework for strategic animal-welfare mitigation planning during a CSF outbreak.

In this study, we quantitatively evaluated two movement-restriction strategies for FAD outbreak control control—that of complete movement restriction and that of controlled movement restriction—and focused on their impacts on adverse animal-welfare conditions. We developed robust risk assessment models using Indiana swine industry data and CSF as a disease model. Our risk models generated outbreak-related measures, including the time when animal-welfare conditions tend to emerge, the number of swine premises that are under movement restrictions that would encounter animal-welfare problems, frequency of on-farm euthanasia and the movement of pigs to slaughter plants, the amount of euthanasia that must be performed in order to alleviate adverse animal-welfare conditions, and the risk of secondary outbreaks due to movement of pigs to slaughter plants.

Objectives: We proposed to develop and employ risk assessment models to systematically and quantitatively assess the impacts of movement restriction on foreign animal disease (FAD) outbreak management on animal welfare in the U.S. pork industry. The movement control policies that we evaluated included (a) complete movement restriction (i.e., standstill); (b) controlled movement within premises; (c) controlled movement among and between premises; and (d) controlled movement from premises to slaughter plants. The animal-welfare related parameters that we investigated included the time it took for a facility to reach a critical overcrowding condition, other stress factors (e.g., feed/water shortage, density of animal, facility type), the time it took to initiate controlled movement, risk of disease transmission, outbreak monitoring, and mortality and morbidity.

The first objective of the study was to identify target parameters and establish a qualitative risk model. The outcome of this objective was a concept framework describing the roles of each selected parameter and the relationships among them. The framework contained nodes that represented a specific control measure and branches that connected between two control measures. These branches represented the direct associations between the connected control measures. This framework visually presents structured information on planning animal-movement-related policies during a FAD outbreak for decision makers and pork industry stakeholders.

The second objective was to estimate parameter distributions using existing databases. The framework that we constructed in the previous objective was used to identify model parameters of interest. We collected information and elicited the probability distribution for each of the model parameters. The results of this objective may assist decision makers in improving current data collection processes and address important but overlooked measures to inform future data needs. The documentation of existing surveillance data also provides other potential users opportunities for an easy adaption and update on our models with the latest available data.

The third study objective was to develop stochastic risk assessment models to quantitatively evaluate different movement-control policies for FAD outbreak management. The end products from this project would allow us to provide evidence-based recommendations to government authorities for optimal control strategies under different FAD outbreak scenarios. In addition, our models may help decision makers and the pork industry identify and estimate costs and resources required to execute the recommended control strategies.

Materials & Methods: To develop the study's conceptual framework that we proposed for the first objective, we conducted a focus group discussion among invited experts in relevant disciplines. The focus group met at Purdue University in June 2014 to review, discuss, and critique the proposed framework. The conceptual framework was revised according to the consensus reached from the discussion. The finalized conceptual framework was used to develop the risk assessment models. The data used to elicit the probability distributions for the model parameters were collected from different sources, including the Indiana swine premises identification database (USAHERDS), the United States Department of Agriculture (USDA) foreign animal disease response plans, and published studies.

We developed two robust risk assessment models. We developed the first model to estimate the time it took for adverse animal-welfare conditions to emerge after the implementation of movement restrictions during a FAD outbreak. We developed the second model to estimate the risk associated with the controlled movement of pigs from movement restriction zones to slaughter plants. We built the risk models in MS Excel and ran the simulations using both the North American Animal Disease Spread Model (NAADSM, 2013) and @RISK (version 7, Ithaca, NY: Palisade Corporation). The NAADSM was used to model disease spread, whereas @RISK program was used to run the stochastic risk assessment models. We implemented different algorithms in the risk models to quantitatively connect the model parameters as described in the conceptual framework. We used the most likely CSF outbreak scenarios in Indiana that we identified using the published risk metric (Yadav et al., 2016) to simulate and estimate outbreak-related parameters, such as epidemic duration and number of infected swine premises. Two types of outbreaks were studied: single-site outbreaks that are initiated from a single location and multiple-site outbreaks that are initiated from more than one location. Figure 1 presents examples of the two types of outbreak and the corresponding control zones. All the simulations and analyses were performed separately for nursery operations and finisher operations.

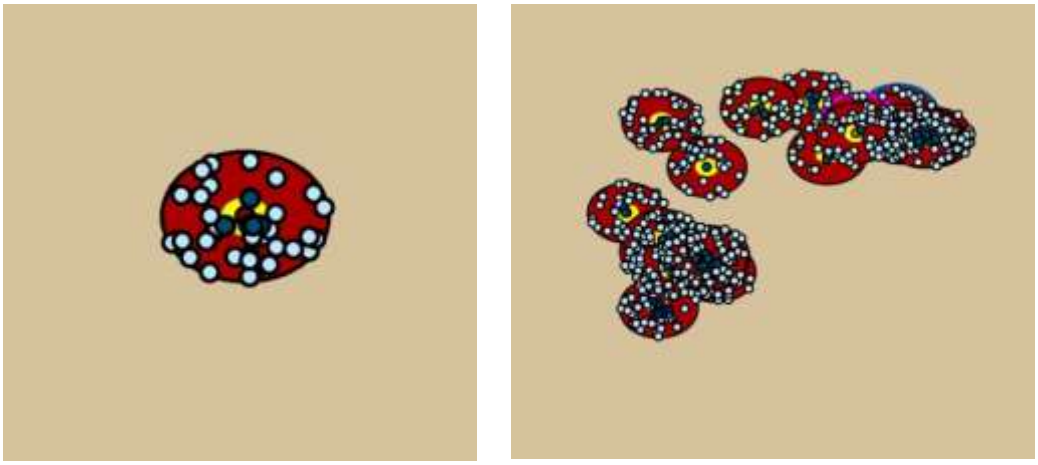

Figure 1. Examples of a single-site outbreak and multiple-site outbreak scenarios. The yellow areas are the infected zones, and the brown areas are the movement restriction zones.

Our goal was to develop robust risk assessment models that could be easily adapted by the stakeholders and updated with the latest available data. To achieve this goal, we applied several assumptions to the models. First, we defined overcrowding as a condition when the total weight of the pigs on a single premises exceeds 100-115% of the maximum capacity of that premises (measured in kg). Thus, this measurement of overcrowding was independent of housing type. Second, we quantitatively modeled the probability for a pork producer's to discontinue feed supply, which would be followed by the euthanasia of pigs. This probability was dependent on (a) the epidemic duration estimated at the onset of an outbreak in which the assumption was that the longer this estimate is, the more likely it is that a producer would decide to discontinue feed supply; (b) the difference between the age of pigs at the onset of the outbreak and their final age at the production phase (i.e., their harvest or transition to the next phase) in which the assumption was that the larger the difference is, the more likely it is that a producer would decide to discontinue feed supply; and (c) the progress

(number of days) of the outbreak, in which the assumption was that the longer the outbreak lasts, the more likely it is that a producer would decide to discontinue feed supply.

Results:

Objective 1: To identify target parameters and establish a qualitative risk model
A total of 17 experts in swine veterinary medicine, animal welfare, pork production, and epidemiology attended the focus group discussion. The discussion focused on pork production, FAD outbreak management, movement-restriction policies, and animal-welfare consequences resulting from movement restriction. During the discussion, we selected overcrowding and feed interruption as the adverse animal-welfare consequences of movement restriction to be modeled in this study. We also decided to exclude controlled movement within and between premises from the project. The finalized conceptual framework is presented in Figure 2.

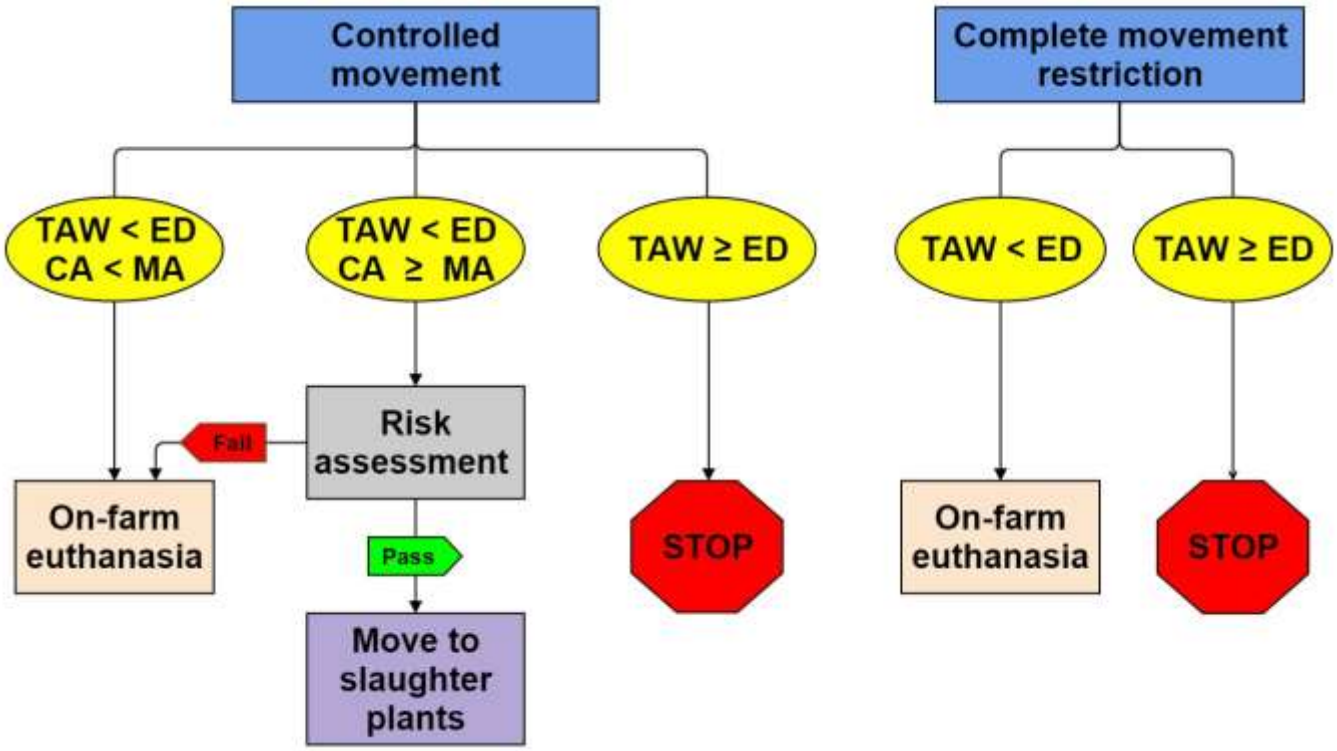

Figure 2. The conceptual framework for the development of risk assessment models to evaluate potential adverse animal-welfare conditions due to movement restrictions and the associated mitigation strategies. Key: *CA*=the age of pigs when adverse animal welfare outcomes emerge; *MA*=market age of pigs; *ED*=epidemic duration; *TAW*=time it takes for adverse animal-welfare conditions to emerge.

As shown in the conceptual framework, the timing for swine premises to encounter overcrowding or feed interruption (i.e., TAW) was compared to the epidemic duration (i.e., ED) to determine which mitigation strategy (i.e., no further action, on-farm euthanasia or movement of pigs to slaughter plants) should be initiated. If overcrowding or feed interruption emerged after an outbreak ended (i.e., TAW ≥ ED), no further action was necessary. If overcrowding or feed interruption emerged before an outbreak ended (i.e., TAW < ED), further alleviation response had to be initiated. Under the complete movement restriction, on-farm euthanasia was the only option to alleviate these conditions. Under the controlled-movement strategy, the age of pigs at the onset of overcrowding or feed interruption (i.e., CA) was compared to the market age of pigs (i.e., MA) to determine the corresponding action. If pigs had not reached market age at the onset of animal-welfare

conditions (i.e., CA< MA), on-farm euthanasia was initiated. Otherwise (i.e., CA ≥ MA) the pigs were moved to a slaughter plant after passing the pre-movement risk assessment. If the risk assessment identified suspicious infections on the premises, on-farm euthanasia was initiated. We developed two risk assessment models to estimate the identified parameters (i.e., TAW and pre-movement risk assessment) based on this conceptual framework.

Objective 2: To estimate parameter distributions using existing databases

Table 1 summarizes the information on the key input model parameters for the risk assessment models. The table also shows the data sources for the estimates of parameter distributions. The compiled and documented parameter distribution list provides crucial information for the adaption and updates on the risk assessment models.

Table 1. Selected model input parameters, probability distributions, and data sources for the study's risk assessment models.

Input parameter	Probability distribution	Data source
Number of pigs on a premises when an outbreak starts (*Intl_numb*)	Lognormal(934, 2282)	Indiana swine premises identification database (USAHERDS)
Harvest/transition season (*Season*)	DUniform(1,2,3)	1: high proportion of reaching harvest/transition 2: moderate proportion of reaching harvest/transition 3: low proportion of reaching harvest/transition
Age (days) of pigs when an outbreak starts (*Intl_age*)	Nursery: If *Season*=1, Triangle(19,50,65) If *Season*=2, Triangle(19,40,65) If *Season*=3, Triangle(19,30,65) Finisher: If *Season*=1, Triangle(40,150,165) If *Season*=2, Triangle(40,100,165) If *Season*=3, Triangle(40,50,165)	USAHERDS, (USDA, 2002, 2014)
Mortality rate per day (*Death_rate*)	If *Intl_age*<=40, Triangle(0.0012,0.00138,0.00152) If *Intl_age*>40, Triangle(0.0001,0.0005,0.001)	(Maes et al., 2001; de Grau et al., 2005)
Final age (days) of production phase (*Fnl_age*)	Nursery: Triangle(42,65,70)) Finisher: Triangle(150,165,180))	(USDA, 2002)
A factor applied to the maximum capacity to	Pert(0.85,0.95,1)	

allow leeway for occurrence of 'overcrowding' after reaching the final age of production phase (*Capacity_adj_factor*)		
Epidemic duration (*ED*)	Triangle(29,192,514)	(Yadav et al., 2016)
Length of time that a swine premises owner could tolerate to not increase the chance of discontinuing feed supply (*Tolerance_fc*)	Nursery: IntUniform(14,46) Finisher: IntUniform(30,125)	
Probability to discontinue feed supply (*Pr_Fdc*)	Low: Bernoulli(0.05); 1 for discontinue High: Bernoulli(0.30); 1 for discontinue	
Feed storage capacity (*Feed_storage*)	IntUniform(2,14)	

Objective 3: To develop stochastic risk assessment models to quantitatively evaluate different movement control policies for FAD outbreak management

Figure 3 is a snapshot of one of the risk assessment models that we built in MS Excel. These models are available by request.

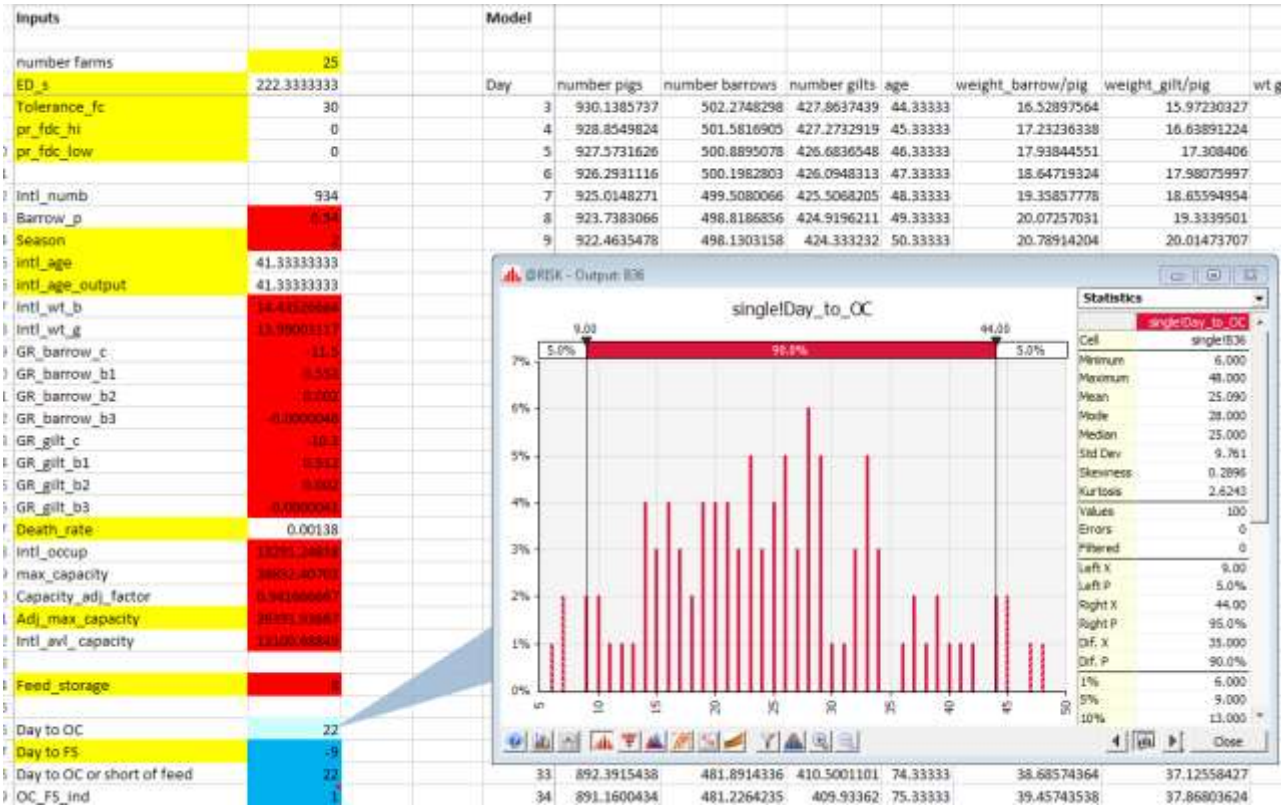

Figure 3. This risk assessment model estimates the time it takes for adverse animal-welfare conditions to emerge due to movement restrictions. The algorithms are implemented in the model columns. The inserted histogram shows the stochastic nature of the model.

Time to adverse animal-welfare conditions

Because the results of single-site and multiple-site outbreak scenarios are very similar, only the results of multiple-site outbreaks are reported. The median time for overcrowding or feed interruption to emerge on the swine premises within movement restriction zones was 18 (the 25th and 75th percentiles: 10-28) days among nursery operations and 57 (13-94) days among finisher operations. As shown in Figure 4, most of the nursery operations under movement restrictions would encounter overcrowding or feed interruption within 50 days of a CSF outbreak compared to about 50% of the finisher operations.

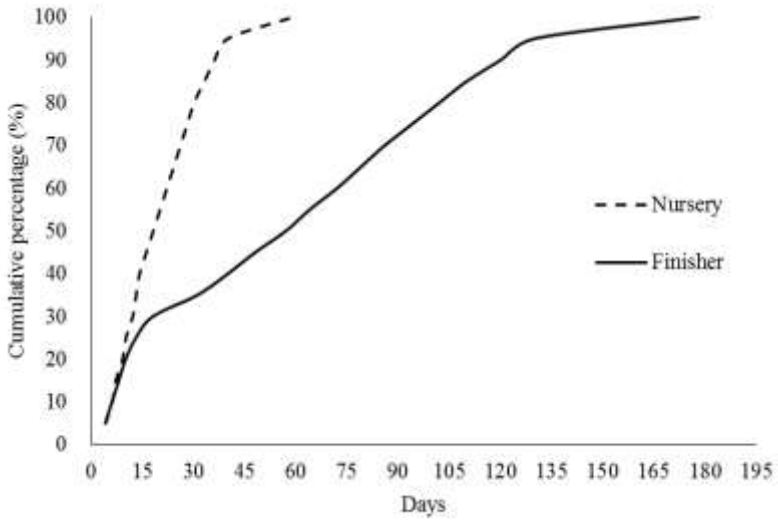

Figure 4. Cumulative percentage of the swine premises, by two types of operations, under movement restrictions that encountered overcrowding or feed interruption by days after the onset of a CSF outbreak.

Extent of adverse animal-welfare conditions and associated mitigation strategies in Indiana

The results reported here were estimated using the 2012 Indiana USAHERDS data. A total of 8,631 swine premises were included in the USAHERDS, and among them, approximately 14% were commercial operations (N=1394; herd size range: 200–20,000 with a median of 2,300). The risk model estimated that approximately 9% and 23% of the swine premises in Indiana would encounter adverse animal-welfare conditions due to movement restrictions in the instance of a single-site outbreak and a multiple-site outbreak, respectively. Among them, approximately 5% were nursery operations and 95% were finisher operations. Given that the median herd size of commercial swine premises in Indiana was 2,300 pigs, we estimated that approximately 0.27 million (single-site) to 0.70 million (multiple-site) pigs in commercial operations would experience these adverse animal-welfare conditions during a CSF outbreak in Indiana. Under complete movement restriction, all pigs that encountered these adverse animal-welfare conditions would have to be euthanized on farm to alleviate the conditions. If controlled movements were allowed, the model estimated that on-farm euthanasia needed to be performed on approximately 33% of the swine premises that encountered overcrowding or feed interruption. We estimated that the movement of pigs to slaughter plants would need to be initiated on 67% of the premises to alleviate the adverse animal-welfare conditions. Furthermore, we estimated that almost 90% of on-farm euthanasia needed to be carried out within the first two weeks of the implementation of movement restriction. On the contrary, only 7% of the movement of pigs to slaughter plants needed to be initiated within the first four weeks of the movement restriction.

Pre-movement risk assessment

Based on the data and the risk assessment model, we estimated that in Indiana, approximately 6 to 15% of swine premises would need to initiate movement of pigs to slaughter plants to alleviate adverse animal-welfare conditions. To prevent secondary outbreaks due to these movements, our model estimated that seven pigs from each shipment should be sampled and tested for CSF infections. This sample size would allow the inspector to detect at least one infected pigs in any given shipment with 99% confidence. Furthermore, each swine premises should be allowed to have up to five shipments during an outbreak to maintain the maximum allowable risk level.

Discussion: In this project, we evaluated two movement-restriction strategies for FAD outbreak control—namely, complete movement restriction and controlled movement restriction—and emphasized their impacts on adverse animal-welfare conditions. As was demonstrated in this study, overcrowding and feed interruption could pose immediate challenges to pork producers and disease-outbreak-control officers during a CSF outbreak. Allowing the movement of market-age pigs to slaughter plants after pre-movement risk assessment could greatly relieve the pressure on producers and government authorities to execute on-farm euthanasia to alleviate these adverse animal-welfare conditions and reduce economic loss. This recommendation is supported by our findings that the controlled movement of pigs to slaughter plants could be used to alleviate approximately 67% of the swine premises that encounter overcrowding or feed interruption. Our models further indicate that the risk of secondary outbreaks due to these movements is very low.

When a foreign animal disease outbreak such as CSF emerges, owners of swine premises that fall within a movement restriction zone must make critical decisions quickly. To make informed decisions about how to maximize profits and minimize losses, pork producers have to integrate the available information on the characteristics of premises (e.g., production type and how far the pigs are from the harvest/transition age) as well as different outbreak-related parameters (e.g., estimated epidemic duration and outbreak-control measures that ought to be imposed). Thus, providing timely and accurate information on outbreak-related estimates to pork producers is a crucial task for outbreak-control authorities. Therefore, one of our goals for the project was to develop robust yet empirically supported risk assessment models for easy adoptions by decision makers (e.g., government authorities) using routinely collected surveillance data on swine premises. To achieve this goal, we developed the model algorithms for detecting the emergence of overcrowding on premises by assuming that pork producers would maximize the utility of facility capacity. Specifically, overcrowding was defined as a condition in which the total weight of all pigs on premises exceeds 100−115% of that maximum capacity of the premises. This assumption aligns with the majority of modern intensive pork-production operations in Indiana. Our models are robust and do not require information on the dimensions or types of individual housing facilities to determine overcrowding. Because the facility-specific information on the dimensions and types of swine housing is not routinely collected in swine-premises surveillance in the United States, our model algorithms allowed for the broader application of any size or type of swine premises. This robustness is critical in planning foreign animal disease outbreak control, because it must cover extensive geographic areas at a state and national level.

The early onset of adverse animal-welfare conditions during a CSF outbreak could greatly hamper outbreak management because the execution of mitigation strategies, such as on-farm euthanasia, would require competing resources for other outbreak-control activities (East et al., 2014). Thus, mitigation strategies for alleviating the animal-welfare consequences of movement restriction must be thoroughly planned as part of the contingency plan for foreign animal disease outbreak control. The strategies should ensure the proper distribution of limited resources for outbreak management. To aid in CSF contingency planning, the temporal distribution of overcrowding and feed interruption derived from our risk model were combined with the Indiana swine data. We did so to estimate the number of nursery and finisher premises under movement

restrictions that would experience adverse animal-welfare conditions by days during a CSF outbreak. Our estimates supported the implementation of controlled movements of market-age pigs to slaughter plants during a CSF outbreak among the premises that operated inside the movement restriction zones. Because the risk of secondary outbreaks due to such movements was estimated to be very low, only a small sample of pigs (n=7) in each shipment would need to be sampled and tested for CSF infection to detect the presence of at least one infected pig. The estimates that we derived from our models can be used to estimate the amount and scale of required resources for executing investigated mitigation strategies and to conduct a cost-benefit analysis for evaluating different CSF outbreak-control strategies.

In summary, our study's risk assessment models revealed that overcrowding and feed interruption are likely to emerge on the swine premises that operate under movement restrictions at an early stage of a CSF outbreak. The demands of the early onset of adverse animal-welfare conditions may compete for resources with other-disease control activities and hamper outbreak-control progress. The recommendation of the controlled movement of market-age pigs to slaughter plants was supported by our models; this can be a low-risk alternative to complete movement restriction. Allowing controlled movement of healthy pigs to slaughter plants could greatly relieve emotional and economic burdens on pork producers who operate under movement restrictions.

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