THESIS

VACCINATION STRATEGIES FOR A FOOT-AND-MOUTH DISEASE OUTBREAK IN SOUTHWEST KANSAS

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY BRIAN DEAN GREATHOUSE ENTITLED VACCINATION STRATEGIES FOR A FOOT-AND-MOUTH DISEASE IN SOUTHWEST KANSAS BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT OF THESIS

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Globalization has expanded market opportunities for U.S. livestock producers. With the increase in world travel and globalization of agriculture, the possibility of transmitting a highly contagious foreign animal disease to the U.S. is higher. Therefore, it is critically important to develop and assess economic implications of emergency management plans in the event a contagious livestock disease outbreak was to occur in the U.S.

For example, the United Kingdom experienced a severe FMD outbreak in 2001. By the end of the outbreak, 221 days after it started, 2,026 cases of FMD had been confirmed, over six million animals were destroyed, and the disease had spread to Ireland, France, and the Netherlands. Thompson et al. (2002) estimated losses from FMD in the UK at £5.8 to £6.3 billion ($8.47 to $9.20 billion U.S.).

Responding to public opposition in the UK to the eradication measures, as well as the demand for an alternative destruction approach because of limited carcass disposal due to concerns about water (burial) or air pollution by smoke (burning), the USDA's Animal and Plant Health Inspection Service (APHIS) – Veterinary Service (VS) recently unveiled its vision for the future called *VS 2015*. According to APHIS (2009), VS 2015 "will allow the organization to place greater emphasis on disease prevention,

preparedness, detection and early response activities" (page 1). There are several forces driving this initiative and its focus: diseases that were once eradicated or controlled are beginning to emerge again, changes in the industry structure (an increase in the number of large-scale, production-intensive operations), advances in technology, public awareness of diseases, demand for protein (especially in developing countries), and shrinking federal budgets (which has an increased emphasis on optimal allocation of resources).

Combining APHIS's *VS 2015* vision and the recent advances in FMD vaccines, it is imperative that policies are developed with input from both the epidemiological and economic sciences. The purpose of this study is to estimate the epidemiological and economic impacts associated with the various emergency vaccination strategies in the event of a FMD outbreak in a large cattle feeding region, where large-scale depopulation activities might not be feasible. In this study, we will compare the impacts of using vaccination as a way to control the spread of FMD on the time of detection and across herd size.

Additionally, we investigate the changes in producer and consumer welfare associated with: the optimal timeframe in which officials have to begin the vaccination strategy; and destruction or alternative marketing channels for vaccinated animals (i.e., what happens if all vaccinated animals are destroyed vs. if the vaccinated animals are not destroyed.)

To achieve the objectives of this study, a stochastic epidemiological disease spread model is used to simulate a hypothetical FMD outbreak outside of this thesis. Results from the disease spread model are then incorporated into an equilibrium

displacement model (EDM). The EMD is a set of supply and demand equations that incorporates multiple commodities, multiple marketing levels within the farm-retail marketing chain, and international trade.

The results obtained from the epidemiological model indicate that varying the number of herds detected before vaccination commenced had a minor impact on the number of animals destroyed, number of animals vaccinated and the length of the outbreak. The economic results suggest that no vaccination has the smallest decline in producer welfare when compared to the vaccination scenarios. Varying the number of herds detected before vaccination begins has little impact on producer and consumer welfare. When destroying the vaccinated animals, the impacts are larger at the producer levels compared to the scenarios when animals are not destroyed. As would be expected, when the export markets are closed longer, the impacts are larger. The various scenarios studied suggest the total producer meat surplus decreases between $15,810.6 and $21,324.9 million. The total consumer meat surplus decreases $2,581.8 and $5,875.6 million.

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The past two years have been so memorable with my fellow graduate students. Although I could not list all those who have influenced my time here, I will mention a few. Thank you John, Luke, Jenny, Katie and Erin for making office life and social gatherings lively, entertaining, and unforgettable.

Dedication

I would like to dedicate this research to my family. Without their overall guidance and encouragement for me to succeed, I would not have been able to accomplish what I have today. Their love and support cannot be acknowledged enough. They have been their throughout my life and studies here, and will continue to be through my life. Thank you so much.

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Chapter 1 - Introduction

The United States has been free of foot-and-mouth disease (FMD) for 80 years. Since the last FMD outbreak in 1929, the U.S. livestock industry has seen tremendous growth. Part of this growth can be attributed to U.S. export markets. In 2008, the U.S. exported over three million metric tons of red meat which is valued at approximately $8.5 billion (US Export Meat Federation, 2008).

In late 2003, the U.S. experienced verifiable impacts of a less economically important animal disease than FMD, bovine spongiform encephalopathy (BSE). BSE was discovered in an infected dairy cow in Washington State, and later in beef cattle in Texas and Alabama. The discovery of BSE in 2003 in Washington State led to 90% of the U.S. export markets being closed upon discovery (Rich and Winter-Nelson, 2007). The majority of the economic loss from BSE came from the closing of the export markets, and confirms the need to integrate trade shocks into any economic model.

FMD is considered to be the most economically important livestock disease in the world. The United Kingdom confirmed a FMD case on February 20, 2001. Scudamore and Harris (2002) found that by the time the disease was discovered, it had spread to at least 57 premises. They concluded that by the time the disease was eradicated it was believed to infect over 10,000 premises in Great Britain and Northern Ireland resulting in over 6.5 million animals being slaughtered for disease control. Thompson et al. (2002) estimated losses from FMD in the UK at £5.8 to £6.3 billion which in U.S. dollars is $7.5 to $8.21 billion (in 2009 U.S. $). The FMD outbreak in the UK in 2001 was largely concentrated in the sheep industry, which in the UK is very comparable to the U.S. beef industry, where you have a supply chain system which includes dealers, markets, and movements.

The concern regarding U.S. vulnerability of either FMD being introduced inadvertently or deliberately has become more heightened as a result of higher prevalence of FMD throughout the world, an increase in globalization and the September 11th 2001 terrorist attacks. Recognizing the importance of minimizing the vulnerability of a contagious animal disease outbreak, such as FMD, the USDA's Animal and Plant Health Inspection Service (APHIS) – Veterinary Service (VS) recently unveiled its vision for the future called *VS 2015*. According to USDA-APHIS (2009), VS 2015 "will allow the organization to place greater emphasis on disease prevention, preparedness, detection and early response activities" (page 1). For the U.S. to be prepared for a highly contagious animal disease outbreak, it is important for policy makers and animal health officials to have several management strategies at their disposal when dealing with FMD because the magnitude of disease spread is uncertain.

There are numerous management strategies when dealing with contagious livestock diseases. Two strategies that have been used in previous FMD outbreaks throughout the world are stamping-out (destruction of infected animals) and vaccination or a combination of the two. While both stamping-out and vaccination are designed to control and eradicate the spread of FMD, vaccination does not require the destruction of the animals which could affect the nation's demand and supply for that product. Yet, when a country chooses to vaccinate for FMD, they do face the possibility of longer export restrictions (OIE, 2008).

This research focuses on a concentrated cattle feeding region in Kansas. In 2007, more than 22% of all U.S. beef originating from Kansas beef processing facilities was from cattle fed in Kansas (USDA-NASS, 2007). According to USDA-NASS's Cattle on Feed Report (2009), Kansas is the third largest state in the U.S. for cattle on feed with approximately 2.5 million as of January 1, 2008. Kansas had approximately 4.4 million head that were attributed to inflows from other states from January 1, 2007 through January 1, 2008 (USDA-NASS, 2008). These large shipments of cattle into the state could only further the disease outbreak. Kansas is a state which is heavily influenced by its livestock industry. The fed cattle and pork industry accounts for nearly 63% of the State's income (USDA-NASS, 2009). Pairing this information with the densely populated feedlot industry located in southwest Kansas, makes this region an ideal choice to evaluate the epidemiological and economic impacts of alternative control strategies in a hypothetical FMD outbreak.

Objective Statement

The main objective of this research is to determine and understand the possible changes in producer and consumer welfare due to various management strategies of an FMD outbreak in southwest Kansas. In particular, this research will investigate the impacts of alternative FMD vaccination strategies. The vaccination strategies examined include: (1) varying the number of herds that are detected before animal health officials begin vaccinating (i.e., 1 herd vs. 5 herds are detected before vaccination begins) and (2) the decision of whether or not to destroy vaccinated animals (i.e., impacts if all vaccinated animals are destroyed vs. if the vaccinated animals are not destroyed). These vaccination scenarios will be compared to the baseline disease control scenario which is depopulation of known infected herds only. The epidemiological output from the North American Animal Diseases Spread Model will be used with a multi-market simulation model to estimate the economic impacts due to the hypothetical outbreak.

Organization of Thesis

The following chapter presents an overview of FMD and concludes with a review of previous research in the areas of disease spread and economic impacts resulting from FMD outbreaks. Chapter Three will discuss the epidemiological model used to simulate the spread of FMD in Kansas. Chapter Four will describe the theoretical and economic framework used in estimating the economic impacts of a FMD outbreak. Chapter Five will discuss the data used in the research. The results and conclusions will be presented in Chapters Six and Seven, respectively

Chapter 2 - Literature Review

The literature review will be divided into two sections: (1) a brief overview of FMD and (2) previous research that has focused on the economic impacts of vaccination strategies in a FMD outbreak.

Overview of Foot and Mouth Disease

Foot-and-mouth disease is a highly contagious disease which is found in cloven foot animals such as cattle, sheep, goats, swine, deer, and elk. Because a majority of protein and milk producing livestock animals are highly susceptible to FMD, FMD is among the most contagious diseases in livestock to the world.

The foot-and-mouth disease virus was discovered in 1897 by Loeffer. The virus can persist in contaminated material and the environment for up to one month depending on conditions (USDA-APHIS, 2009). Transmission of the virus can occur through direct or indirect contact including humans and vehicles, and has been found to transmit through the air. Animals that have been infected with the disease will typically begin to show clinical signs within 2 to 5 days. Some clinical signs include: fever, blisters, excess salvation, and lameness. There is a very low mortality rate, but a high morbidity rate.

The Office International des Epizooties (OIE), which serves as the leading information source for animal diseases and outbreaks for the world, was established in 1924 to help countries prevent and control animal disease outbreaks by providing them with relevant and current scientific research. The OIE also assists the World Trade

Organization by providing documents that assist with international trade regulations when dealing with livestock and related products.

Due to the highly contagious nature of FMD, the OIE has suggested trade restrictions for an FMD infected country. Once a country loses their FMD free status, a country should follow the OIE Terrestrial Animal Code to regain FMD free status.

When an FMD outbreak occurs in an FMD free country, where *routine vaccination is not being practiced*, one of the following waiting periods is required by the OIE to regain the status of FMD free country:

1) three months after the last case where a stamping-out policy and serological surveillance are applied in accordance with Appendix 8.5.40 to 8.5.46.
2) three months after slaughter of all vaccinated animals where a stamping-out policy, emergency vaccination and serological surveillance are applied in accordance with Appendix 3.8.7.
3) six months after the last case or the last vaccination (according to the event that occurs last), where a stamping-out policy, emergency vaccination not followed by the slaughtering of all vaccinated animals, and serological surveillance are applied in accordance with Appendix 3.8.7., provided that a serological survey based on the detection of antibodies to nonstructural proteins of FMDV demonstrates the absence of infection in the remaining vaccinated population (OIE Terrestrial Animal Code, 2008) .

When a FMD outbreak occurs in a FMD free country where *routine vaccination is practiced*, one of the following waiting periods is required by the OIE to regain the FMD free status:

1) Six months after the last case where a stamping-out policy, emergency vaccination and serological surveillance in accordance with Appendix 3.8.7 are applied provided that the serological surveillance based on the detection of antibodies to nonstructural proteins of FMDV demonstrate the absence of virus circulation.

2) 18 months after the last case where a stamping-out policy is not applied, but emergency vaccination and serological surveillance in accordance with Appendix 3.8.7 are applied provided that serological surveillance based on the detection of antibodies to nonstructural proteins of FMDV demonstrates the absence of virus circulation (OIE Terrestrial Animal Code, 2008).

Past Economic and Epidemiological FMD Studies

Berentsen, Dijkhuizen, and Oskam (1992) investigated the economic impacts of a FMD outbreak in Dutch cattle and pig herds due to a ban on exports. A state-transmission model was used to simulate the disease spread. Two FMD control strategies were evaluated: (1) annual vaccination of the cattle population; and (2) no annual vaccination. The economic framework used was a cost-benefit analysis combined with an export model. These models accounted for the losses to the producers, consumers, and government. Strategies that did not use annual vaccination were found to be preferable to annual vaccination in terms of the economic implications because of the trade restrictions.

Garner and Lack (1995) looked at the role of regional factors in determining the impact of a FMD outbreak and control strategies needed to eradicate FMD from three separate regions in Australia. Four disease control options for FMD were considered: (1) stamping-out; (2) dangerous contact slaughter; (3) early ring vaccination; and (4) late ring vaccination. The authors used a stochastic disease simulation model to generate outbreak scenarios. An input-output model was used to calculate the direct and indirect economic impacts. Garner and Lack (1995) found that early ring vaccination was effective in reducing the duration and size of the outbreak, but that strategy was found to be less efficient, when compared with stamping-out alone.

Randolph et al. (2002) investigated the effects of control and eradication of FMD in the Philippines which was working to achieve FMD free status at that time. A spatial disease spread model was used to assist in evaluating the impacts of eradication and control measures in the Philippines. The control and eradication protocol used in the Philippines was a combination of ring vaccination, movement control and enhanced bio-security. A cost-benefit analysis was used to evaluate the economic implications of different eradication strategies. The authors concluded the eradication of FMD in the Philippines would be an economically viable investment because the gains from exports would outweigh the costs of FMD eradication.

Ekboir (1999) investigated strategies to control a FMD outbreak in three counties within the Central Valley of California. The epidemiological model used was a state-transition model that incorporated five health states: (1) susceptible; (2) infected but not showing clinical signs; (3) infected and showing clinical days; (4) immune; and (5) depopulated. The economic framework consisted of three components: (1) direct costs of depopulating, cleaning and disinfecting, and enforcement of quarantine; (2) direct and indirect costs to California through an input-output model (IMPLAN); and (3) losses incurred due to trade restrictions. The epidemiological and economic models were used to evaluate several alternative control strategies: (1) partial stamping-out (remove only infected animals) with and without ring vaccination; (2) total stamping-out with ring vaccination; and (3) vaccination only. Total losses estimated could range from $6.7 to $13.5 billion, depending on the scenario.

Schoenbaum and Disney (2003) created a stochastic simulation framework to simulate a FMD outbreak in the U.S. The framework included both epidemiological and economic models. The scenarios investigated included three vaccination and four stamping-out methods paired with two speeds of FMD spread. The authors based the disease spread on previous research by Morris et al. (2001), which set slow-spread scenarios at less than 2 km and 4 km per day for fast spread. When selecting the optimal control strategy, the most significant variables were the speed of the spread of FMD and demographics of the animal population. Schoenbaum and Disney (2003) also found that destruction of direct contact herds was less costly than slaughtering only contagious herds. Additionally, depopulation in 3 km rings was more costly than other depopulation strategies. Ring vaccination was found to have a lower cost to the government and appeared to slow the spread. However, when vaccinated animals were destroyed, it was found to be more costly due to indemnity and other related slaughter costs.

Bates, Carpenter, and Thurmond (2003) developed a cost-benefit analysis for vaccination and preemptive slaughter in a FMD outbreak in central California. The authors looked at the direct costs of indemnity, slaughter, and cleaning and disinfecting costs comparing across different eradication strategies. The authors found that if the vaccine is effective, then vaccination is cost effective. Additionally, they concluded that vaccination can be a cost-effective strategy for control of FMD if the vaccinated animals are not slaughtered and there are no future economic losses, such as trade restrictions.

Pendell et al. (2007) examined the local economic impact of a hypothetical FMD outbreak in southwest Kansas, an area with high density of cattle feeding. In the three scenarios that were examined, FMD was introduced into a cow-calf operation, a small-to-medium sized feedlot operation and simultaneously in five large feedlots. The authors used an equilibrium displacement model and IMPLAN to estimate the regional impacts. They found that if an outbreak was introduced into five large feedlots in southwest Kansas, Kansas could expect an economic loss of $1 billion dollars compared to $200 million if introduced into a small-to-medium size feedlot and $35 million in a cow-calf operation, respectively.

Kobayashi et al. (2007) investigated alternative FMD control strategies in a three county region of the Central Valley in California. The epidemiological model discussed in Bates, Carpenter, and Thurmond (2003) was used in this study. The model minimized the total regional epidemic costs by choosing the most efficient levels of depopulation, preemptive depopulation, and vaccination. The authors found that preemptive depopulation was not optimal. However, vaccination, if allowed, was optimal by reducing total costs between 3-7%. Greater vaccination capacity was found to reduce costs up to $119 per head. The authors also reported that dairies should be given preferential treatment when allocating limited resources.

Rich and Winter-Nelson (2007) looked at a FMD outbreak in the Southern Cone of South America which includes Argentina, Uruguay and Paraguay. They developed an integrated epidemiological-economic model of animal disease control that is both dynamic and spatial. The authors concluded that within the Southern Cone of South America, the benefits differ from varying disease control policies in certain regions. It was also noted that the short- and long-run time horizons were impacted by the policy differences between regions.

Contribution of the Study

The research discussed throughout the rest of this thesis is similar to the articles above in several ways. For example, a disease spread model is used to determine the severity of a hypothetical FMD outbreak using alternative mitigation strategies. These results are then incorporated into an economic model to determine changes in welfare measures.

Although this research is similar to past work, there are some differences. This study focuses on a highly dense cattle feeding region as did Pendell (2006) and Pendell et al. (2007). Pendell (2006) and Pendell et al. (2007) investigated the impacts of alternate levels of traceability and FMD introduction scenarios, respectively. The focus in this work is evaluating alternate mitigation strategies with focus on vaccination in a highly dense cattle feeding region. Additionally, the partial equilibrium model used distinguishes between different marketing levels, allows for consumer substitutability at the retail level, and incorporates international trade.

Chapter 3 - Epidemiology Model

Following the 2001 FMD outbreak in the UK, the North American Foot-and-Mouth Disease Vaccine Bank organized a workshop to identify suitable disease spread models that would assist in effective policy formulation for North America. From these meetings, the North American Animal Disease Spread Model (NAADSM) was created. This model was highly influenced by the disease spread model created by Schoenbaum and Disney (2003) because of its user friendliness. NAADSM, like many models before, is a spatially explicit, stochastic, state-transition model.

Harvey et al. (2007) explains that NAASDM is driven by stochastic processes which are based on distributions and relational functions which can be specified by the user. The model uses probability density functions to represent the duration of disease states and distance of animal movements.

NAASDM has eight main input parameters which include: (1) units; (2) disease; (3) spread; (4) disease detection; (5) tracing out; (6) control measures; (7) priorities of actions; and (8) costs. The animal *unit* is a herd or group of animals at a given location. Each herd contains the location, number of animals in the herd, production type, and initial disease state. There are five health or *disease* states in which herds are categorized: susceptible, latently infected, infectious and subclinically infected, infectious and clinically infected, and immune. *Spread* can occur through direct contact among herds, indirect contact via movement of people, vehicles, etc., and through airborne spread. There are two probabilities that contribute to *disease detection*: the probability that producers and practitioners will diagnose FMD and the probability the proper authorities will be notified. Once an infected herd is detected, the user can specify the number of days (and the probability of a successful trace) a susceptible herd comes in contact with an infected herd, also referred to as *tracing out*. There are three disease *control measures*: quarantine, destruction, and vaccination. Vaccination is the control measure of interest in this study. Because many events can happen simultaneously, the user can *prioritize the actions* (e.g., if two different production types are to be destroyed, one production type will take priority over another production type.). Direct *costs* associated with destruction and vaccination can be calculated by the model (Harvey et al., 2007). These input parameters can be modified by the user depending on the focus of the research. The input parameters used in the study can be found in the Appendix.

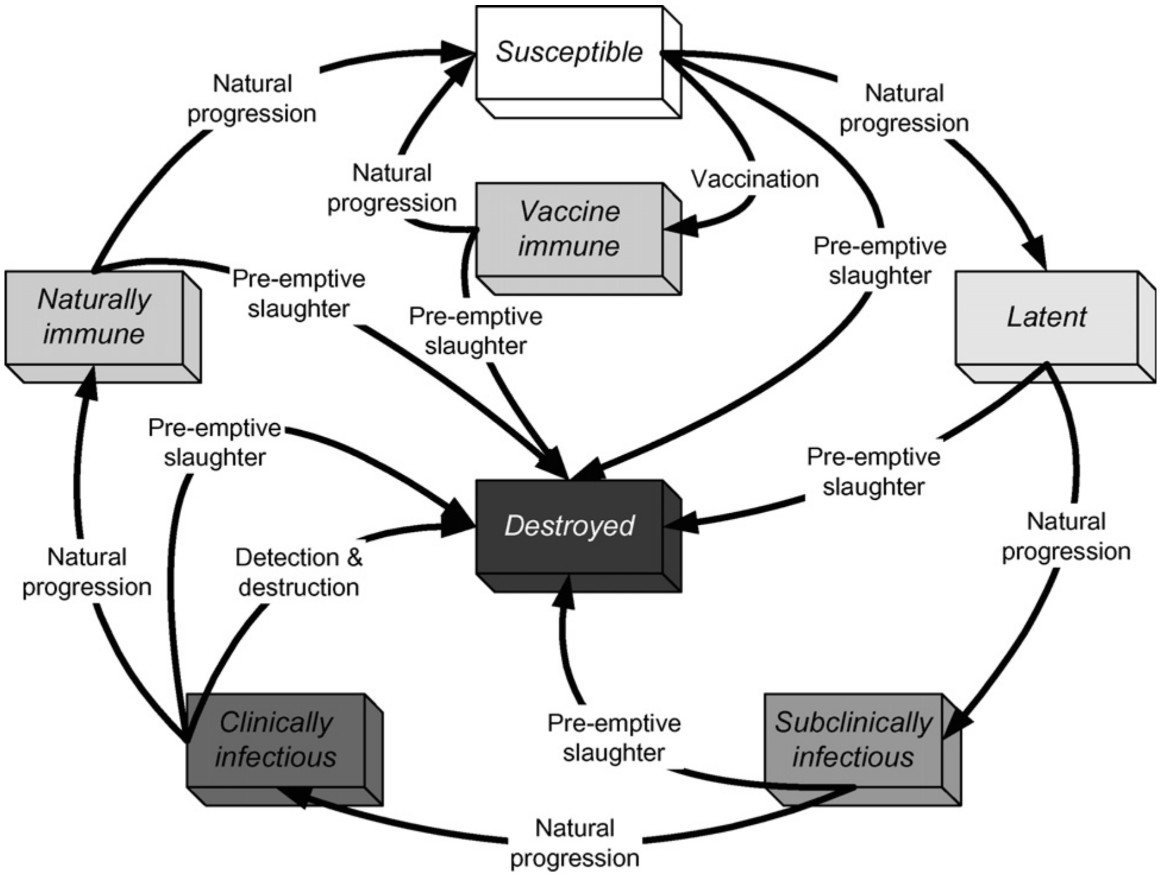

Figure 3.1 NAADSM's health states and transitions (source: Harvey et al., 2007)

As described above, control measures in NAASDM include: quarantine, destruction, and vaccination. The vaccination input parameters allows the users to choose: (1) to vaccinate or not to vaccinate; (2) vaccination capacity; and (3) the radius of ring vaccination. Vaccination capacity allows the user to set the number of herds that can be vaccinated in a day. Vaccination capacity for this study is set at the onset of the FMD outbreak (i.e., day zero) to one herd per day, and at day 14, the vaccination capacity increases linearly to three herds per day for the remainder of the outbreak. Vaccination is administered in the form of ring vaccination. That is, when a critical number of detected herds has been reached (i.e., 1, 5, 10 or 20 herds), a vaccination ring occurs around the detected units. Ring vaccination in this study focused on 3 km rings. A larger ring of 5 km was used, but the radius of the spread did not have significant impacts on the outcome.

The research focused on the output from five different scenarios: (1) destruction of known infected herds only without vaccination; (2) ring vaccination after 1 herd has been detected; (3) ring vaccination after 5 herds have been detected; (4) ring vaccination after 10 herds have been detected; and (5) ring vaccination after 20 herds have been detected. By creating four different herd detection scenarios, this will allow us to see if there is a threshold number of herds detected before vaccination will have no effect on slowing or stopping the outbreak. This will also allow us to compare the vaccination scenarios (described above) to the scenario for which vaccination does not occur.

The output from these scenarios should be of importance to animal health officials because of the new intentions spelled out in “VS 2015.” Output from NAASDM will demonstrate the impacts vaccination has on the number of animals destroyed, length of outbreak which is broken down into (1) length of the disease phase of the epidemic and (2) length of time for all tasks related to the outbreak to finish (e.g., finish destroying all herds), and the number of vaccinations needed.

Chapter 4 - Economic Modeling Strategy

This chapter will begin with an overview of the most popular economic models used in assessing animal disease outbreaks. Next, the structural model used to describe the supply and demand equations for the U.S. beef, pork, lamb, and poultry livestock sectors will be presented. To quantify the consumer and producer welfare changes, a multi-market simulation equilibrium displacement model is constructed and discussed for the U.S. livestock and meat industry. Economic assessment of an animal disease outbreak plays an important role in understanding the output from the epidemiological models. There has been an increasing amount of research that links epidemiological and economic models, which has led to an enrichment of the literature. Rich, Miller, and Winter-Nelson (2005) present an overview of five types of economic models used in conjunction with epidemiological models: (1) benefit-cost analysis; (2) linear programming; (3) partial equilibrium analysis; (4) input-out; and (5) computable general equilibrium model.

Benefit-cost analysis (BCA) is a popular tool used to measure the costs of disease outbreaks under alternative control measures. Results from the BCA are typically summarized through net present value or a benefit-cost ratio. The BCA approach is useful at the farm level and is easy to use, but is not linked to other sectors of the economy and is not well suited for use on a broader scale due to the use of fixed budgets (Rich, Miller, and Winter-Nelson, 2005).

Linear programming (LP) is another tool used to minimize or maximize an objective function (minimize costs or maximize profits). An advantage of this method when compared to BCA is it allows for a range of different activities with the model determining the optimal combination of activities. Risk can easily be incorporated into the LP model. Although this method has advantages over the BCA approach, LP is less frequently used because of the data requirements (Rich, Miller, and Winter-Nelson, 2005).

Partial equilibrium analysis is a mathematical representation of supply and demand equations. The partial equilibrium analysis maximizes producer and consumer welfare measures subject to constraints, which are embedded in the demand and supply equations. Although the partial equilibrium analysis cannot provide detail information at farm-level like the BCA, the partial equilibrium analysis can measure changes in prices and quantities, which are used to estimate welfare changes, and can be linked across markets (Rich, Miller, and Winter-Nelson, 2005).

Another popular economic tool used in modeling impacts of animal health events is the input-output (I-O) model. The I-O method is based on budgets and accounting relationships. One advantage of the I-O models is the ability to capture the flows of inputs and outputs of an economy, including the linkages between different economic sectors. However, it cannot effectively capture the inputs and outputs at the farm level and is not effective when looking at long-term effects. Additionally, the effects in a I-O model are attributed to changes in demand, not supply (Rich, Miller, and Winter-Nelson, 2005.

The final economic framework discussed in Rich, Miller, and Winter-Nelson (2005) is a computable general equilibrium (CGE) model. The CGE models are used to analyze the economy wide impacts. This method incorporates aspects of the I-O and partial equilibrium models. An advantage of the CGE model is its ability to capture linkages across sectors and the amount of information that is provided by the model. Although the method proves more information, the amount of information can be overwhelming and the imprecise nature of the accounting matrix (and multipliers) can give inaccurate estimates (Rich, Miller, and Winter-Nelson, 2005).

This study will use a partial equilibrium analysis approach. Several past studies have used a partial equilibrium model to study animal health issues. Berentsen, Dijkhuizen, and Oskam (1992) used a single sector, multilevel model of the hog industry in the Netherlands to evaluate alternate FMD control measures. Rich and Winter-Nelson (2007) used a multi-sector and multi-level model to estimate the impacts of alternate FMD control measures in the Southern Cone of South America (Argentina, Uruguay, and Paraguay). Zhao, Wahl, and Marsh (2006) used a single sector, multi-market level model of the U.S. beef industry to analyze impacts of alternate traceability and vaccination in an FMD outbreak. Schoenbaum and Disney (2003) used a multi-sector to estimate the changes in welfare for alternate FMD control strategies. Paarlberg et al. (2008) used a multi-sector and multi-market level model to evaluate the impacts on different control strategies in the U.S. Because of the importance of animal health events (in regards to producers, consumers, and governments), research linking epidemiological and economic modeling is becoming more common.

Modeling Strategy

The partial equilibrium model used in this research assumes that a hypothetical FMD outbreak will have a supply shock on U.S. livestock marketing sectors. Additionally, a demand shock is incorporated by temporarily closing beef and pork export markets, one realistic scenario based on past outbreaks in this sector. To conclude, this section discusses the final producer and consumer welfare implications from the supply and demand shocks.

In the event of a FMD outbreak, both producers and consumers could gain or lose surplus because of a reduced supply of livestock and an increased amount of meat on the domestic market due to closures of export markets. Producer surplus is defined as the difference between the amount that a producer receives for their product and the minimum amount they would be willing to accept for that good. The change in producer surplus is measured by the following equation (Alston, Norton, and Pardey, 1995):

1) $$\Delta PS_i^k = P_i^k Q_i^k [E(P_i^k) + \beta_i^k][1 + 0.5E(Q_i^k)].$$

Where PS represent producer surplus. Price and quantity are represented by *P* and *Q*, respectively. Subscript *i* indicates the commodity (beef, pork, lamb, and poultry) while the superscript *j* indicates the marketing level (retail, wholesale, slaughter, and farm), respectively. β represents the supply shock while *E* is the percentage change operator.

Consumer surplus is the difference between the maximum total purchase price a consumer would be willing to pay and the actual purchase price of a product. The change in consumer surplus is measured by the following equation (Alston, Norton, and Pardey, 1995):

2) $\Delta CS_i = -P_i^k Q_i^k [E(P_i^k) - \alpha_i^k][1 + 0.5E(Q_i^k)]$

where CS represent consumer surplus. α represents the demand shock. The remaining variables are defined above.

Structural Model

A set of supply and demand equations that link the beef, pork, lamb, and poultry industries together provide the framework for the equilibrium displacement model. The current research, which is building on Pendell et al. (2010), allows for production quantities to vary across market levels. The model incorporates variable input proportions by allowing quantities to vary across marketing levels (Pendell et al., 2010; Brester, Marsh, and Atwood, 2004; Wohlgenant, 1989). The model also allows for consumer substitution among meat products at the retail level.

The structural model is broken down into four sectors: retail (consumer), wholesale (processor), slaughter (market cattle, market hogs, and market lambs), and farm (feeder cattle and feeder lambs). The beef industry is marketed within all four of the sectors of the structural model. The pork industry only has three marketing levels (retail, wholesale, and slaughter) because the hog industry is more integrated than the cattle industry. The lamb industry is similar to the beef industry in the sense it is not as integrated as the hog and poultry industry. The U.S. lamb industry model assumes all four, farm-retail marketing sectors. The poultry industry is highly integrated, and for that reason, only the retail and wholesale levels are considered in the model. Presented below is a structural supply and demand model for U.S. beef, pork, lamb, and poultry industries.

Beef Sector:

Retail

3) U.S. retail beef demand: $Q_B^r = f_1(P_B^{rd}, P_K^{rd}, P_{Ld}^{rd}, P_{Li}^{rd}, P_Y^{rd}, Z_B^{rd})$

4) U.S. retail beef supply: $Q_B^r = f_2(P_B^{rs}, Q_B^w, W_B^{rs})$

Wholesale

5) U.S. wholesale beef demand: $Q_B^w = f_3(P_B^{wd}, Q_B^r, Z_B^{wd})$

6) Export wholesale beef demand: $Q_{Be}^{wd} = f_4(P_B^{wd}, Z_{Be}^{wd})$

7) Import wholesale beef demand: $Q_{Bi}^{wd} = f_5(P_{Bi}^{wd}, Q_B^w, Z_{Bi}^{wd})$

8) U.S. wholesale beef supply: $Q_B^w = f_6(P_B^{ws}, Q_B^s, Q_{Be}^{wd}, Q_{Bi}^{ws}, W_B^{ws})$

9) Import wholesale beef supply: $Q_{Bi}^{ws} = f_7(P_{Bi}^{ws}, W_{Bi}^{ws})$

Slaughter

10) U.S. fed cattle demand: $Q_B^s = f_8(P_B^{sd}, Q_B^w, Z_B^{sd})$

11) U.S. fed cattle supply: $Q_B^s = f_9(P_B^{ss}, Q_B^f, W_B^{ss})$

Farm

12) U.S. feeder cattle demand: $Q_B^f = f_{10}(P_B^{fd}, Q_B^s, Z_B^{fd})$

13) U.S. feeder cattle supply: $Q_B^f = f_{11}(P_B^{fs}, W_B^{fs})$

Pork Sector:

Retail

14) U.S. retail pork demand: $Q_K^r = f_{12}(P_B^{rd}, P_K^{rd}, P_{Ld}^{rd}, P_{Li}^{rd}, P_Y^{rd}, Z_K^{rd})$

15) U.S. retail pork supply: $Q_K^r = f_{13}(P_K^{rd}, Q_K^w, W_K^{rd})$

Wholesale

16) U.S. wholesale pork demand: $Q_K^w = f_{14}(P_K^{wd}, Q_K^r, Z_K^{wd})$

17) Export wholesale pork demand: $Q_{Ke}^{wd} = f_{15}(P_{K,}^{wd} Z_{Ke}^{wd})$

18) Import wholesale pork demand: $Q_{Ki}^{wd} = f_{16}(P_{Ki,}^{wd} Q_K^w, Q_{Ke}^{wd}, Q_{Ki}^{ws}, Z_{Ki}^{wd})$

19) U.S. wholesale pork supply: $Q_K^w = f_{17}(P_K^{ws}, Q_K^s, W_K^{ws})$

20) Import wholesale pork supply: $Q_{Ki}^{ws} = f_{18}(P_{Ki}^{ws}, W_{Ki}^{ws})$

Slaughter

21) U.S. market hog demand: $Q_K^s = f_{19}(P_K^{sd}, Q_K^w, Z_K^{sd})$

22) Import market hogs demand: $Q_{Ki}^{sd} = f_{20}(P_{Ki}^{sd}, Q_K^s, Z_{Ki}^{sd})$

23) U.S. market hog supply: $Q_K^s = f_{21}(P_K^{ss}, Q_{Ki}^{ss}, W_K^{ss})$

24) Import market hog supply: $Q_{Ki}^{ss} = f_{22}(P_{Ki}^{ss}, W_{Ki}^{ss})$

Lamb Sector:

Retail

25) U.S. retail lamb demand: $Q_{Ld}^r = f_{23}(P_B^{rd}, P_K^{rd}, P_Y^{rd}, P_{Li}^{rd}, P_{Ld}^{rd}, Z_{Ld}^{rd})$

26) U.S. retail lamb supply: $Q_{Ld}^r = f_{24}(P_L^{rs}, Q_L^w, W_L^{rs})$

27) Import retail lamb demand: $Q_{Li}^r = f_{25}(P_{Li}^{rd}, P_B^{rd}, P_K^{rd}, P_Y^{rd}, P_{Ld}^{rd}, Z_{Li}^{rd})$

28) Import retail lamb supply: $Q_{Li}^r = f_{26}(P_{Li}^{rs}, W_{Li}^{rs})$

Wholesale

29) U.S. wholesale lamb demand: $Q_L^w = f_{27}(P_L^{wd}, Q_{Ld}^r, Z_L^{wd})$

30) U.S. wholesale lamb supply: $Q_L^w = f_{28}(P_L^{ws}, Q_L^s, W_L^{ws})$

Slaughter

31) U.S. market lamb demand: $Q_L^s = f_{29}(P_L^{sd}, Q_L^w, Z_L^{sd})$

32) U.S. market lamb supply: $Q_L^s = f_{30}(P_L^{ss}, Q_L^f, W_L^{ss})$

Farm

33) U.S. feeder lamb demand: $Q_L^f = f_{31}(P_L^{fd}, Q_L^s, Z_L^{fd})$

34) U.S. feeder lamb supply: $Q_L^f = f_{32}(P_L^{fs}, W_L^{fs})$

Poultry Sector:

Retail

35) U.S. retail poultry demand: $Q_Y^r = f_{33}(P_B^{rd}, P_K^{rd}, P_{Ld}^{rd}, P_{Li}^{rd}, P_Y^{rd}, Z_Y^{rd})$

36) Export retail poultry demand: $Q_{Ye}^{rd} = f_{34}(P_Y^{wd}, Z_{Ye}^{wd})$

37) U.S. retail poultry supply: $Q_Y^r = f_{35}(P_Y^{rs}, Q_Y^w, W_Y^{rs})$

Wholesale

38) U.S. wholesale poultry demand: $Q_Y^w = f_{36}(P_Y^{wd}, Q_Y^r, Z_Y^{wd})$

39) U.S. wholesale poultry supply: $Q_Y^w = f_{37}(P_Y^{ws}, W_Y^{ws})$

Table 4.1 lists the definitions of the variables for the structural and equilibrium displacement models. Variable X_{il}^{jk} represent price and quantity for which *j* represents marketing level (i.e., *r* = retail, *w* = wholesale, *s* = slaughter, and *f* = feeder). The superscript *k* indicates either a demand function (*d*) or a supply function (*s*). The subscript *i* represents the species (i.e., *B*=beef, *K*=pork. *L*=lamb, and *Y*=poultry). Lastly, the subscript *l* represents either an import (*i*) or export (*e*), where appropriate.

Table 4.1. Definitions of Variables used in the Structural and Equilibrium Displacement Models

Variable	Definitions
P^R_B	Retail price of beef
Q^R_B	Quantity of beef at the retail level
P^W_B	Wholesale price of beef
Q^W_B	Quantity of beef at the wholesale level
Q^W_{Be}	Quantity of beef at the export wholesale level
P^W_{Bi}	Wholesale price of beef imports
Q^W_{Bi}	Quantity of beef at the import wholesale level
P^S_B	Slaughter price of beef
Q^S_B	Quantity of fed cattle at the slaughter level
P^F_B	Feeder cattle price at the farm level
Q^F_B	Quantity of feeder cattle at the farm level
P^R_K	Retail price of pork
Q^R_K	Quantity of pork at the retail level
P^W_K	Wholesale price of pork
Q^w_K	Quantity of pork at the wholesale level
Q^W_{Ke}	Quantity of pork at the wholesale export level
P^W_{Ki}	Wholesale price of pork imports
Q^w_{Ki}	Quantity of pork at the wholesale import level
P^S_K	Slaughter price of pork
Q^S_K	Quantity of fed hogs at the slaughter level
P^S_{Ki}	Slaughter price of pork imports
Q^S_{Ki}	Quantity of fed hogs at the import slaughter level
P^R_{Ld}	Price of domestic retail lamb
Q^R_{Ld}	Quantity of lamb at the domestic retail level
P^R_{Li}	Price of retail lamb imports
Q^R_{Li}	Quantity of lamb at the import retail level
P^W_L	Wholesale price of lamb
Q^W_L	Quantity of wholesale lamb
P^S_L	Slaughter price of lamb
Q^S_L	Quantity of fed lambs at the slaughter level
P^F_L	Feeder lamb price at the farm level
Q^F_L	Quantity of feeder lambs at the farm level
P^R_Y	Retail price of poultry
Q^R_Y	Quantity of poultry at the retail level
Q^R_{Ye}	Quantity of poultry at the export retail level
P^W_Y	Wholesale price of poultry
Q^W_Y	Quantity of poultry at the wholesale level
Z^j_i	Demand shifters for the *i*th commodity at the *j*th marketing level
W^j_i	Supply shifters for the *i*th commodity at the *j*th marketing level

Equilibrium Displacement Model

One commonly used tool in agricultural economics is the equilibrium displacement model (EDM). The EDM has been used to analyze the estimated the impacts on the U.S. pork industry of an introduction of a new growth hormone (Lemieux and Wohlgenant, 1989). Brester, Marsh and Atwood, (2004) and Lusk and Anderson (2004) used the EDM model to show the welfare effects of country-of-origin-labeling in the U.S. meat industry. Balagtas and Kim (2007) used a multi-market equilibrium displacement model in the dairy sector to show the effects of generic dairy marketing. Rickard and Sumner (2008) used an equilibrium displacement model to demonstrate the effects of agriculture trade policies on the global processing tomato markets. Pendell et al. (2010) estimated the impacts of adoption of animal identification on livestock and meat producers and consumers. The EDM has been used extensively in international trade issues (e.g., Beghin, Brown, and Zaini (1997), Duffy and Wohlgenant (1991), and Sumner Alston, and Gray (1994)) and evaluating welfare effects of advertising and promotion (e.g., Piggott (2003), Cranfield (2002), and Richards and Patterson (2000)).

An equilibrium displacement model is a linear approximation of unknown demand and supply functions. The accuracy of the model depends largely on the degree of nonlinearity of the supply and demand functions and magnitude of deviations from the equilibrium. Past research by Brester, Marsh, and Atwood (2004), Brester and Wohlgenant (1997), and Wohlgenant (1993) indicates that the supply and demand functions are only accurate when the deviations are relatively small because the model is a linear model.

To develop an EDM model, equations (3) - (39) are totally differentiated, and converted to elasticity form which results in the following equilibrium displacement model:

Beef Sector:

Retail Level

40) $EQ_B^r = \eta_B^r EP_B^r + \eta_{BK}^r EP_K^r + \eta_{BLd}^r EP_{BLd}^r + \eta_{BLi}^r EP_{Li}^r + \eta_{BY}^r EP_Y^r + Ez_B^r$

41) $EQ_B^r = \varepsilon_B^r EP_B^r + \tau_B^{wr} EQ_B^w + Ew_B^r$

Wholesale Level

42) $EQ_B^w = \eta_B^w EP_B^w + \tau_B^{rw} EQ_B^r + Ez_B^w$

43) $EQ_B^w = \varepsilon_B^w EP_B^w + (Q_{Bi}^w / Q_B^w) EQ_{Bi}^w - \left(Q_{Be}^w / Q_B^w\right) EQ_{Be}^w + Ew_B^w$

44) $EQ_{Be}^w = \eta_{Be}^w EP_B^w + Ez_{Be}^w$

45) $EQ_{Bi}^w = \eta_{Bi}^w EP_{Bi}^w + \tau_B^{rw} EQ_B^w + \left(Q_{Be}^w / Q_B^w\right) Ez_{Be}^w + Ez_{Bi}^w$

46) $EQ_{Bi}^w = \varepsilon_{Bi}^w EP_{Bi}^w + Ew_{Bi}^w$

Slaughter Level

47) $EQ_B^s = \eta_B^s EP_B^s + \tau_B^{ws} EQ_B^w + (Q_{Be}^w / Q_B^w) Ez_{Be}^w + Ez_B^s$

48) $EQ_B^s = \varepsilon_B^s EP_B^s + \tau_B^{fs} EQ_B^f + Ew_B^s$

Farm Level

49) $EQ_B^f = \eta_B^f EP_B^f + \tau_B^{sf} EQ_B^s + Ez_B^f$

50) $EQ_B^f = \varepsilon_B^f EP_B^f + Ew_B^f$

Pork:

Retail Level

51) $EQ_K^r = \eta_{KB}^r EP_B^r + \eta_K^r EP_K^r + \eta_{KLd}^r EP_{Ld}^r + \eta_{KLi}^r EP_{Li}^r + \eta_{KY}^r EP_Y^r + Ez_K^r$

52) $EQ_K^r = \varepsilon_K^r EP_K^r + \tau_K^{wr} EQ_K^w + Ew_K^r$

Wholesale Level

53) $EQ_K^w = \eta_K^w EP_K^w + \tau_K^{rw} EQ_K^r + Ez_K^w$

54) $EQ_K^w = \varepsilon_K^w EP_K^w + (Q_{Ki}^w / Q_K^w) EQ_{Ki}^w - \left(Q_{Ke}^w / Q_K^w\right) EQ_{Ke}^w + Ew_K^w$

55) $EQ_{Ke}^w = \eta_{Ke}^w EP_K^w + Ez_{Ke}^w$

56) $EQ_{Ki}^w = \eta_{Ki}^w EP_{Ki}^w + \tau_K^{rw} EQ_K^w + (Q_{Ke}^w / Q_K^w) Ez_{Ke}^w + Ez_{Ki}^w$

57) $EQ_{Ki}^w = \varepsilon_{Ki}^w EP_{Ki}^w + Ew_{Ki}^w$

Slaughter Level

58) $EQ_K^s = \eta_K^s EP_K^s + \tau_K^{ws} EQ_K^w + (Q_{Ke}^w / Q_K^w) Ez_{Ke}^w + Ez_K^s$

59) $EQ_K^s = \varepsilon_K^s EP_K^s + (Q_{Ki}^s / Q_K^s) EQ_{Ki}^s + Ew_K^s$

60) $EQ_{Ki}^s = \eta_{Ki}^s EP_{Ki}^s + \tau_K^{ws} EQ_K^s + Ez_{Ki}^w$

61) $EQ_{Ki}^s = \varepsilon_{Ki}^s EP_{Ki}^s + Ew_{Ki}^s$

Lamb Sector:

Retail Level

62) $EQ_{Ld}^r = \eta_{Ld}^r EP_{Ld}^r + \eta_{LdLi}^r EP_{Li}^r + \eta_{LdB}^r EP_B^r + \eta_{LdK}^r EP_K^r + \eta_{LdY}^r EP_Y^r + Ez_{Ld}^r$

63) $EQ_{Ld}^r = \varepsilon_{Ld}^r EP_{Ld}^r + \tau_L^{wr} EQ_L^w + Ew_{Ld}^r$

64) $EQ_{Li}^r = \eta_{LiLd}^r EP_{Ld}^r + \eta_{Li}^r EP_{Li}^r + \eta_{LiB}^r EP_B^r + \eta_{LiK}^r EP_K^r + \eta_{LiY}^r EP_Y^r + Ez_{Li}^r$

65) $EQ_{Li}^r = \varepsilon_{Li}^r EP_{Li}^r + Ew_{Li}^w$

Wholesale Level

66) $EQ_L^w = \eta_L^w EP_L^w + \tau_L^{rw} EQ_{Ld}^r + Ez_L^w$

67) $EQ_L^w = \varepsilon_L^w EP_L^w + \tau_L^{sw} EQ_L^s + Ew_L^w$

Slaughter Level

68) $EQ_L^s = \eta_L^s EP_L^s + \tau_L^{ws} EQ_L^w + Ez_L^s$

69) $EQ_L^s = \varepsilon_L^s EP_L^s + \tau_L^{fs} EQ_L^f + Ew_L^s$

Farm Level

70) $EQ_L^f = \eta_L^f EP_L^f + \tau_L^{sf} EQ_L^s + Ez_L^f$

71) $EQ_L^f = \varepsilon_L^f EP_L^f + Ew_L^f$

Poultry:

Retail Level

72) $EQ_Y^r = \eta_Y^r P_Y^r + \eta_{YB}^r EP_B^r + \eta_{YK}^r EP_K^r + \eta_{YLd}^r EP_{Ld}^r + \eta_{YLi}^r EP_{Li}^r + Ez_Y^r$

73) $EQ_{Ye}^r = \eta_{Ye}^r EP_Y^r + Ez_{Ye}^r$

74) $EQ_Y^r = \varepsilon_Y^r EP_Y^r + \tau_Y^{wr} EQ_Y^w - (Q_{Ye}^r / Q_Y^r) EQ_{Ye}^r + Ew_Y^r$

Wholesale Level

75) $EQ_Y^w = \eta_Y^w EP_Y^w + \tau_Y^{rw} EQ_Y^r + (Q_{Ye}^r / Q_Y^r) Ez_{Ye}^r + Ez_Y^w$

76) $EQ_Y^w = \varepsilon_Y^w EP_Y^w + Ew_Y^w$.

The term *E* in the above equations represent present change (i.e., $EQ_B^r = dQ_B^r / Q_B^r = d\ln(Q_B^r)$). The demand and supply shock is represented by (Z_i^j) and supply by (W_i^j), respectively. The parameters ε, η, and τ are elasticities which are defined in table 4.2.

Elasticities and exogenous supply and demand shocks are used in equations 40 - 76 to determine the relative change in the endogenous quantities and prices. To estimate the changes in quantities and prices, equations 38-74 can be written in matrix notation as:

77) $\mathbf{Y} = \mathbf{A}^{-1} * \mathbf{X}$

where **A** is the matrix of elasticities, **Y** is the vector of changes in the endogenous prices and quantities, and **X** is a vector of exogenous supply and demand shifts.

Elasticity Estimates

To determine the percentage changes in prices and quantities, market parameters or elasticities are required. There have been several approaches used to determine the required elasticities: (1) econometrically estimate the values, 'calibrate' or 'guestimate' the values using theory and intuition, or borrow from past studies (James and Alston, 2002). Similar to recent studies (Brester, Marsh, Atwood (2004), Lusk and Anderson (2004), Balagtas and Kim (2007), Rickard and Sumner (2008), and Pendell et al. (2010)), this research used elasticities from extant literature. The elasticity values used in this research are reported in table 4.2.

Davis and Espinoza (1998) demonstrated the importance of conducting sensitivity analysis on prices and quantities in an equilibrium displacement model. Because the elasticity values used are taken from previous literature, this study will extend Davis and Espinoza's work by imposing probability distributions on the elasticities used in the EDM to generate stochastic estimates for prices and quantities, as well as consumer and producer welfare measures.

The simulated elasticities were truncated, with negative demand elasticities and positive supply elasticities, to conform to economic theory. The elasticities used were obtained from past studies; however, most did not report the variance of elasticities. The standard deviation was calculated using the t-values (if present). When the t-values were not available, the average coefficient of variation of 0.16 for demand and 0.13 for supply was used (Brester, Marsh, and Atwood, 2004). These coefficients were then used to establish end points for a uniform distribution which are 3 standard deviations away from the mean. Because standard deviations were available for beef, lamb, and transmission elasticities, Beta (4, 4) distributions were used. Uniform distributions were used on pork and poultry elasticities due to the lack of standard deviation information. All Monte Carlo simulations are the result of 1,000 iterations. The results from the simulated changes in the endogenous price and quantity variables and welfare measures are presented in Chapter 6.

Table 4.2. Parameter Definitions, Values, and Sources Used in the Analysis

Parameter	Definition	Value: Short Run	Value: Long Run
η^{r}_{BB}	Own-price elasticity of retail beef demand[a]	-0.86	-1.17
η^{r}_{BK}	Cross-price elasticity of retail beef demand w.r.t. pork price[a]	0.10	
η^{r}_{BLd}	Cross-price elasticity of retail beef demand w.r.t. domestic retail price[c]	0.05	
η^{r}_{BLi}	Cross-price elasticity of retail beef demand w.r.t. imported retail lamb price[c]	0.05	
η^{r}_{BY}	Cross-price elasticity of retail beef demand w.r.t. poultry price[a]	0.05	
η^{r}_{KY}	Cross-price elasticity of retail pork demand w.r.t. poultry price[h]	0.02	
η^{r}_{YB}	Cross-price elasticity of retail poultry demand w.r.t. to beef price[h]	0.18	
η^{r}_{YK}	Cross-price elasticity of retail poultry demand w.r.t. to pork price[h]	0.04	
η^{r}_{YLd}	Cross-price elasticity of retail poultry demand w.r.t. to domestic retail lamb price[c]	0.02	
η^{r}_{YLi}	Cross-price elasticity of retail poultry demand w.r.t. to imported retail lamb price[c]	0.02	
η^{s}_{B}	Slaughter cattle own-price derived demand elasticity[b]	-0.40	-0.53
η^{f}_{B}	Farm-level own-price derived demand elasticity[b]	-0.14	-0.75
η^{w}_{K}	Wholesale pork own-price derived demand elasticity[d]	-0.71	-1.00
η^{r}_{K}	Own-price elasticity of demand for retail pork[a]	-0.69	-1.00
η^{s}_{K}	Slaughter hogs own-price derived demand elasticity[e]	-0.51	-1.00
η^{w}_{Y}	Wholesale poultry own-price derived demand elasticity[d]	-0.22	-1.00

Table 4.2. Parameter Definitions, Values, and Sources Used in the Analysis, Cont.

Parameter	Definition	Value Short Run	Value Long Run
η_B^r	Own-price derived retail beef supply elasticity[d]	0.36	4.62
η_B^w	Own-price derived wholesale beef supply elasticity[d]	0.28	3.43
ε_B^s	Own-price derived slaughter cattle supply elasticity[f]	0.26	3.24
ε_B^f	Own-price derived feeder cattle supply elasticity[g]	0.22	2.82
ε_K^r	Own-price derived retail pork supply elasticity[d]	0.73	3.87
ε_K^w	Own-price derived wholesale pork supply elasticity[d]	0.44	1.94
ε_K^s	Own-price derived slaughter hogs supply elasticity[h]	0.41	1.8
ε_Y^r	Own-price derived retail poultry supply elasticity[d]	0.18	13.1
ε_Y^w	Own-price derived wholesale poultry supply elasticity[d]	0.14	14.0
ε_{Be}^w	Export demand elasticity for beef at wholesale level[c]	-.42	-3.00
ε_{Ke}^w	Export demand elasticity for pork at wholesale level[c]	-0.89	-1.00
ε_{Ye}^w	Export demand elasticity for poultry at wholesale level[c]	-0.31	-1.00
ε_{Bi}^w	Import demand elasticity for beef at wholesale level[c]	-0.58	-0.94
ε_{Ki}^w	Import demand elasticity for pork at wholesale level[c]	-0.71	-1.00
ε_{Ki}^s	Import demand elasticity for slaughter hogs[c]	-1.00	
ε_{Ki}^w	Import supply elasticities for pork at wholesale level[c]	1.41	10.00

Table 4.2. Parameter Definitions, Values, and Sources Used in the Analysis, Cont.

Parameter	Definition	Value Short Run	Value Long Run
ε_{Ki}^{s}	Import supply elasticities for pork at slaughter level[c]	1.60	4.13
n_{LdK}^{r}	Cross-price elasticity of demand for domestic retail lamb w.r.t. the price of retail pork[c]	0.02	
n_{LdY}^{r}	Cross-price elasticity of demand for domestic retail lamb w.r.t. the price of retail poultry[c]	0.02	
ε_{Ld}^{r}	Own-price elasticity of supply for domestic retail lamb[b]	0.15	3.96
n_{Li}^{r}	Own-price elasticity of demand for imported lamb[b]	-0.41	-0.63
n_{LiLd}^{r}	Cross-price elasticity of demand for imported retail lamb w.r.t. the price of domestic lamb[b]	0.78	
n_{LiB}^{r}	Cross-price elasticity of demand for imported retail lamb w.r.t. the price of retail beef[c]	0.05	
n_{LiK}^{r}	Cross-price elasticity of demand for imported retail lamb w.r.t. the price of retail pork[c]	0.02	
n_{LiY}^{r}	Cross-price elasticity of demand for imported lamb w.r.t. the price of retail poultry[c]	0.02	
ε_{Li}^{r}	Own-price elasticity of supply for imported retail lamb[b]	10.00	10.00
n_{L}^{w}	Own-price elasticity of demand for wholesale lamb[b]	-0.35	-1.03
n_{L}^{w}	Own-price elasticity of supply for wholesale lamb[b]	0.16	3.85
ε_{L}^{s}	Own-price elasticity of demand for slaughter lamb[b]	-0.33	-0.87
n_{L}^{s}	Own-price elasticity of supply for slaughter lamb[b]	0.12	2.95
ε_{L}^{f}	Own-price elasticity of demand for feeder lamb[b]	-0.11	-0.29
n_{L}^{f}	Own-price elasticity of supply for feeder lamb[b]	0.09	2.26

Table 4.2. Parameter Definitions, Values, and Sources Used in the Analysis, Cont.

Parameter	Definition	Short Run
τ_B^{rw}	Percentage change in retail beef supply given a 1% change in wholesale beef supply[c]	0.771
τ_B^{wr}	Percentage change in wholesale beef demand given a 1% change in retail beef demand[c]	0.995
τ_B^{sw}	Percentage change in slaughter cattle demand given a 1% change in wholesale beef demand[c]	1.09
τ_B^{sf}	Percentage change in slaughter cattle supply given a 1% change in feeder cattle supply[c]	1.07
τ_B^{fs}	Percentage change in feeder cattle demand given a 1% change in slaughter cattle demand[c]	0.957
τ_K^{rw}	Percentage change in retail pork supply given a 1% change in wholesale pork supply[c]	0.962
τ_K^{wr}	Percentage change in wholesale pork demand given a 1% change in retail pork demand[c]	0.983
τ_K^{ws}	Percentage change in wholesale pork supply given a 1% change in slaughter hog supply[c]	0.963
τ_K^{sw}	Percentage change in slaughter hog demand given a 1% change in wholesale pork demand[c]	0.961
τ_L^{rw}	Percentage change in retail domestic lamb supply given a 1% change in wholesale lamb supply[c]	0.908
τ_L^{wr}	Percentage change in wholesale lamb demand given a 1% change in retail domestic lamb demand[c]	0.731
τ_L^{ws}	Percentage change in wholesale lamb supply given a 1% change in slaughter lamb supply[c]	1.007
τ_L^{sw}	Percentage change in slaughter lamb demand given a 1% change in wholesale lamb demand[c]	0.993
τ_L^{sf}	Percentage change in slaughter lamb supply given a 1% change in feeder lamb supply[c]	0.864

Table 4.2. Parameter Definitions, Values, and Sources Used in the Analysis, Cont.

Parameter	Definition	Short Run
τ_L^{fs}	Percentage change in feeder lamb demand given a 1% change in slaughter lamb demand[c]	0.962
τ_Y^{rw}	Percentage change in retail poultry supply given a 1% change in wholesale poultry supply[c]	0.806
τ_Y^{wr}	Percentage change in wholesale poultry demand given a 1% change in retail poultry demand[c]	1.035

Sources: [a]Brester and Schroeder (1995); [b]USDA GIPSA Meat Marketing Study (2007); [c]Balsi et al. (2009); [d]Brester, Marsh, and Atwood (2004); [e]Wohlgenant (2005); [f]Marsh (1994); [g]Marsh (2003); [h]Lemieux and Wohlgenant (1989).

Chapter 5 Data

This chapter contains the descriptions and sources of data used in this thesis. The chapter is broken into two sections: (1) epidemiological model and (2) economic model.

Epidemiological Model

The herd level data comes from Pendell (2006). Herd level data consists of location (longitude and latitude), species (feedlot cattle, cow-calf, dairy, and swine) and herd size in southwestern Kansas. The input parameters used in NAASDM are from Premashthira (2009).

Economic Model

The baseline price and quantity data used are annual data from 2008. Retail quantities of beef, pork, lamb, and poultry were calculated by multiplying per capita consumption for each commodity by the U.S. population. The U.S. population data are from the U.S. Census Bureau and provided by the Livestock Marketing Information Center (LMIC). Per capita consumption, wholesale, import and export quantities for beef, pork, lamb and poultry are from LMIC. Retail prices for beef, pork, and poultry are from the USDA Economic Research Service's *Red Meat Price Spread*. Domestic retail lamb and imported retail lamb prices are from the USDA Agriculture Marketing Service's *Livestock, Meat, and Wool*. The last two quarters of 2008 domestic retail lamb, import retail lamb, and wholesale prices had not been updated during the course of the research. Using quarterly price data from 2002-2008, the last two quarters of the 2008 lamb prices were forecasted by regressing the retail price on the price of wholesale lamb.

Wholesale beef price is the average price of boxed beef, grade choice, yield 600-900. Wholesale pork price is pork cut-out value (51-52%) lean hog carcass, while wholesale poultry is broilers 12 city average. Wholesale lamb is lamb carcass price, choice-price, east coast; 55-65 lbs. collected from the USDA AMS *Livestock, Meat, and Wool report*. Quantities for domestic fed cattle (Average Choice 1100-1300 lbs.), market hogs (51-52% lean) and market lambs (Choice-Prime, 55-65 lbs.) are total lbs. marketed and obtained from LMIC. Quantities of domestic feeder cattle, import feeder cattle, and feeder lambs are obtained from LMIC. Prices for fed cattle are Nebraska Market, Average Choice 1100-1300 lbs., market hogs are barrows and gilts, national base 51-52% lean, market and feeder lamb prices are the San Angelo, TX market. The feeder cattle price is the Oklahoma City, 759-800 lbs.. All prices for fed cattle, market hogs, market lambs, feeder cattle, and feeder lambs are from LMIC. Import prices were determined using FATUS Import quantities and Import $ values (USDA FAS). Table 5.1 provides the baseline prices and quantities used in this research.

Table 5.1. Baseline Prices and Quantities, 2008

	Baseline Quantities	Baseline Prices
	(Million lbs.)	($/lb.)
Retail level		
U.S. Beef	19,116.62	4.33
U.S. Pork	15,112.22	2.94
U.S. Lamb	177.90	5.05
Import Lamb	183.29	6.24
U.S. Poultry	25,549.24	1.75
Export Poultry	5,162.66	1.75
Wholesale level		
U.S. Beef	26,668.60	2.35
U.S. Pork	23,369.80	1.24
U.S. Lamb	177.90	2.07
U.S. Poultry	37.42	0.80
Import Beef	1,742.11	1.59
Export Beef	1,865.46	2.35
Import Pork	686.84	1.25
Export Pork	4,623.86	1.24
Slaughter level		
U.S. Fed Cattle	44,060.00	0.92
U.S. Market Hogs	31,210.64	0.47
Import Market Hogs	177.73	0.52
U.S. Lamb	340.00	0.86
Farm level		
U.S. Feeder Cattle	27,084.38	1.03
Import Feeder Cattle	946.47	1.03
U.S. Feeder Lamb	278.25	1.07

Chapter 6 - Results

The results from the modeling are presented below. The results are separated into two sections. The first section contains output from the epidemiological disease spread model while the second section presents the economic results.

Epidemiology Results

The results from NAADSM are expressed as means and standard deviations from 1,000 iterations from each simulation. The output is divided into three parts: (1) total number of animals stamped-out, (2) total number of animals vaccinated, and (3) length of outbreak. Total head stamped-out, vaccinated and length of outbreak are presented by scenario. These scenarios include: (1) destruction of known infected herds only without vaccination (*No Vaccination)*; (2) 3 km ring vaccination after one herd has been infected (*1 Herd)*; and (3) 3 km ring vaccination after 5 herds have become infected (*5 Herds).* Two additional scenarios were evaluated: 3 km ring vaccination after 10 herds have become infected (*10 Herds);* and 3 km ring vaccination after 20 herds have become infected (*20 Herds).* However, there was virtually no difference in the mean, standard deviation, minimum and maximum number of animals stamped-out, vaccinated and length of outbreak between the *5 Herds* and *10 Herds* and *20 Herds* scenarios. Because there is little difference between *5 Herds* and *10 Herds* and *20 Herds*, those results will not be presented or discussed.

Table 6.1 presents the total number of animals destroyed (only known infected animals) for the scenarios described above. The *No Vaccination* scenario stamped-out an average of 2.13 million head of feedlot cattle which is approximately 9% of the total cattle marketed in the U.S. in 2008. Approximately 0.01% of total U.S. calf crop in 2008 or 2,727 head of feeder cattle, and 0.05% of total U.S. marketed in 2008 or 33,183 head of swine were destroyed in the *No Vaccination* scenario. In the *1 Herd* scenario, there was approximately 2.6% (2.18 million head) more feedlot cattle destroyed than *No Vaccination*. Feeder cattle and swine also saw increases of approximately 36% (3,700 head) and 247% (114,982 head), respectively, in the number of animals destroyed in the *1 Herd* scenario when compared to *No Vaccination*. When comparing *1 Herd* to *5 Herds*, there were decreases in the number of animals stamped-out. Specifically, we saw decreases of 3% (2.11 million head), 46% (2,614 head), and 267% (31,288 head) destroyed for feedlot cattle, feeder cattle, and swine, respectively. The results from the disease spread model suggest there is little difference in the average number of animals stamped-out and the length of outbreak across strategies. These epidemiological results are similar (i.e., minor differences across control strategies) to Paarlberg et al. (2008), Pendell (2006) and Schoenbaum and Disney (2003).

The results for the number of animals vaccinated by scenario are presented in Table 6.2. There is a significantly higher number of livestock that are vaccinated in the *1 Herd* scenario compared to *5 Herds, 10 Herds,* and *20 Herds* scenarios. In the *1 Herd* scenario, 854,903 vaccines were administered in feedlot cattle, 22,358 and 231,757 vaccines were needed for feeder cattle and swine, respectively. There was approximately 18% (496,767 vaccines) fewer vaccines needed for feedlot cattle in *5 Herd*. The number of vaccines required for feeder cattle was approximately 55% (14,423 vaccines) less for *5*

Herds. Approximately 165% (87,165 vaccines) fewer vaccines were needed for swine for *5 Herds* when compared to *1 Herd*.

Table 6.3 reports the average number of days until the outbreak is stopped and the average number of days until the outbreak is eradicated. The number of days until the outbreak is stopped (or the length of the active disease phase) ranges from 89 to 98 days on average. There are nine days difference between *No Vaccination* and *1 Herd* scenarios, and four days difference between *1 Herd* and *5 Herds*. The number of days until the outbreak is eradicated (which includes additional time that it takes to complete the control measures) ranges from 104 to 148 days. It takes approximately six additional weeks until the outbreak is eradicated under the *1 Herd* scenario. The length of outbreak in the *5 Herds* scenario is five weeks shorter when compared to *1 Herd*. The maximum number of days until the disease is controlled and eradicated were similar expect for the *1 Herd* scenario, and in this scenario it took approximately 30 days longer until the disease was eradicated.

An interesting result from the disease spread model is the size of the standard deviations for the number of animals stamped-out, number of animals vaccinated, and the length of outbreak, especially for swine. These large values are a result of a high number of simulations having few animals destroyed while, in other simulations, the number of animals stamped-out is very large. Additional research is warranted to analyze the implications of these large standard deviations.

The epidemiological output reported in this thesis suggests there is some difference between *No Vaccination* and *1 Herd* in regards to the number of animal stamped-out and the length of the outbreak. However, when comparing *No Vaccination* to *5 Herds*, the differences appear to be small. These results should be useful for livestock health officials in determining the number vaccinations that might be needed in the event of a FMD outbreak in southwest Kansas.

Table 6.1 Number of Animals Destroyed

	Number of Animals Destroyed			
Scenario	Mean	Std. Dev.	Minimum	Maximum
No Vaccination				
Feedlot Cattle	2,126,015	184,216	6,970	2,271,021
Feeder Cattle	2,727	602	0	4,748
Swine	33,183	131,081	0	961,037
1 Herd Detected 3 km Vaccination Ring				
Feedlot Cattle	2,182,607	63,991	1,984,771	2,273,669
Feeder Cattle	3,700	789	1,962	6,007
Swine	114,982	299,449	0	961,037
5 Herds Detected 3 km Vaccination Ring				
Feedlot Cattle	2,111,890	216,145	6,970	2,268,080
Feeder Cattle	2,614	600	0	4,370
Swine	31,288	121,111	0	958,037

Table 6.2 Number of Animals Vaccinated

	Number of Animals Vaccinated			
Scenario	Mean	Std. Dev.	Minimum	Maximum
1 Herd Detected 3 km Vaccination Ring				
Feedlot Cattle	584,903	92,005	396,209	803,406
Feeder Cattle	22,358	3,666	3,666	32,724
Swine	231,757	89,128	89,128	477,577
5 Herds Detected 3 km Vaccination Ring				
Feedlot Cattle	496,767	92,660	0	742,851
Feeder Cattle	14,423	1,733	0	21,451
Swine	87,165	36,271	0	260,255

Table 6.3 Length of Outbreak

	Days			
Scenario	Mean	Std. Dev.	Minimum	Maximum
No Vaccination				
Days until disease stopped	98	23	8	460
Days until outbreak eradicated	104	21	8	460
1 Herds Detected 3 km Vaccination Ring				
Days until disease stopped	89	15	69	176
Days until outbreak eradicated	148	19	119	205
5 Herds Detected 3 km Vaccination Ring				
Days until disease stopped	93	22	9	420
Days until outbreak eradicated	113	19	9	420

Economic Results

The economic results were simulated by incorporating the epidemiological output from NAASDM into a multi-market displacement model representing the major market sectors for livestock products. The number of animals stamped-out were converted to supply shocks, used in the displacement model and then simulated 1,000 times to give us the percentage change in price and quantity and changes in producer and consumer welfare for beef, pork, lamb, and poultry. Additionally, the length of outbreak was used in determining the length of the export market closure.

Elasticities

Market parameters or elasticities are an essential piece in constructing and estimating an equilibrium displacement model. The elasticity values used in this study are taken from published literature. The elasticity values used in this study are provided in Table 4.2.

Exogenous Shock Estimates

The supply shocks at each marketing level are calculated by using the output from the epidemiological model (number of animals stamped-out) and 2008 baseline price and quantities for each marketing level. Tables 6.4 through 6.6 present the exogenous shocks for each marketing level for the different scenarios. Beef at slaughter level has the largest supply shock among all scenarios which is expected due to the large number of cattle feedlots in the region. Using the average number of slaughter beef stamped-out multiplied by the average slaughter weight gives us, on average, the total weight of slaughter cattle that is stamped-out due to the FMD outbreak. To calculate the total value of slaughter beef stamped-out, total weight of stamped-out slaughter cattle was multiplied by the 2008 baseline price for slaughter beef. The total value of stamp-out cattle was divided by the total value of the slaughter cattle industry. From these calculations, the supply shocks were found to be between 6% and 8%, depending on the scenario. The size of the exogenous supply shocks in this study are similar to those presented in Lusk and Anderson (2004), a 6.5% increase in producers costs resulting from implementation of country-of-origin labeling, and Rickard and Sumner (2008), a 12.2% increase in input supply costs.

With export markets being closed following past FMD outbreaks (e.g., UK in 2001 and 2007, Taiwan in 1997, and Brazil in 2005), this study assumes the export markets will close for U.S. beef and pork. One challenge is to determine the length of an export market ban when a contagious livestock disease outbreak occurs. In this study, the length of the export market ban is the calculated by adding the length of outbreak (in days) to OIE's suggested length of market closure. Because this is an annual economic model, the length of the export market ban is divided by 365 days. In the baseline strategy (*No Vaccination*) and the scenarios that stamp-out vaccinated animals, the loss of the export market for beef and pork in the first year is approximately 53% over 2007 export values. Following OIE guidelines, when vaccinated animals are not stamped-out, the export markets are closed for six months after the end of the outbreak. This increases the losses of beef and pork exports in the first year to approximately 90%. It is assumed when the OIE guidelines are met, U.S. exports of beef and pork fully recover to base levels.

There have been instances when export markets have reopened earlier than the suggested OIE guidelines (e.g., 2001 FMD outbreak in the Netherlands). In this case, the Netherlands used emergency vaccination and did not stamp-out the vaccinated animals, and were able to export to major trading partners within three months, instead of OIE's suggested six months. To assess the impacts of opening export markets before OIEs suggested guidelines, this research analyzed the reopening of export markets three months after the end of the outbreak when vaccinated animals are not destroyed. The loss to the beef and pork export markets in the first year is approximately 65% over 2007 export levels and fully recovered in subsequent periods.

Table 6.4. Exogenous Shock Estimates for the No Vaccination Scenario, Percentage Change

	No Vaccination[a]
Beef	
Retail Demand	0.00
Retail Supply	0.00
Wholesale Demand	0.00
Wholesale Supply	0.00
Wholesale Export Demand	-53.00
Wholesale Import Demand	0.00
Wholesale Import Supply	0.00
Slaughter Demand	0.00
Slaughter Supply	-6.9
Farm Demand	0.00
Farm Supply	-0.01
Pork	
Retail Demand	0.00
Retail Supply	0.00
Wholesale Demand	0.00
Wholesale Supply	0.00
Wholesale Export Demand	-53.00
Wholesale Import Demand	0.00
Wholesale Import Supply	0.00
Slaughter Demand	0.00
Slaughter Supply	-0.03
Slaughter Import Demand	0.00
Slaughter Import Supply	0.00
Lamb	
Retail Demand	0.00
Retail Supply	0.00
Retail Demand Import	0.00
Retail Supply Import	0.00
Wholesale Demand	0.00
Wholesale Supply	0.00
Slaughter Demand	0.00
Slaughter Supply	0.00
Farm Demand	0.00
Farm Supply	0.00
Poultry	
Retail Demand	0.00
Retail Supply	0.00
Retail Demand Export	0.00
Wholesale Demand	0.00
Wholesale Supply	0.00

[a] No Vaccination scenario assumes only the known infected animals are stamped-out and the beef and pork export markets are closed for three months.

Table 6.5. Exogenous Shock Estimates for Vaccination with Depopulation of Vaccinated Animals Scenarios, Percent Change

	1 Herd[a]	*5 Herds*[b]
Beef		
Retail Demand	0.00	0.00
Retail Supply	0.00	0.00
Wholesale Demand	0.00	0.00
Wholesale Supply	0.00	0.00
Wholesale Export	-65.75	-55.57
Wholesale Import	0.00	0.00
Wholesale Import Supply	0.00	0.00
Slaughter Demand	0.00	0.00
Slaughter Supply	-8.02	-7.59
Farm Demand	0.00	0.00
Farm Supply	-0.07	-0.05
Pork		
Retail Demand	0.00	0.00
Retail Supply	0.00	0.00
Wholesale Demand	0.00	0.00
Wholesale Supply	0.00	0.00
Wholesale Export	-65.75	-55.57
Wholesale Import	0.00	0.00
Wholesale Import Supply	0.00	0.00
Slaughter Demand	0.00	0.00
Slaughter Supply	-0.30	-0.10
Slaughter Import Demand	0.00	0.00
Slaughter Import Supply	0.00	0.00
Lamb		
Retail Demand	0.00	0.00
Retail Supply	0.00	0.00
Retail Demand Import	0.00	0.00
Retail Supply Import	0.00	0.00
Wholesale Demand	0.00	0.00
Wholesale Supply	0.00	0.00
Slaughter Demand	0.00	0.00
Slaughter Supply	0.00	0.00
Farm Demand	0.00	0.00
Farm Supply	0.00	0.00
Poultry		
Retail Demand	0.00	0.00
Retail Supply	0.00	0.00
Retail Demand Export	0.00	0.00
Wholesale Demand	0.00	0.00
Wholesale Supply	0.00	0.00

[a] Scenario assumes the known infected & vaccinated animals are stamped-out and the beef and pork export markets are closed for three months.

[b] Depopulation scenario assumes the known infected & vaccinated animals are stamped-out and the beef and pork export markets are closed for three months.

Table 6.6. Exogenous Shock Estimates for Vaccination with No Depopulation of Vaccinated Animals Scenarios, Percentage Change

	1 Herd (3 Months)[a]	*1 Herd (6 Months)*[b]	*5 Herds (3 Months)*[a]	*5 Herds (6 Months)*[b]
Beef				
Retail Demand	0.00	0.00	0.00	0.00
Retail Supply	0.00	0.00	0.00	0.00
Wholesale Demand	0.00	0.00	0.00	0.00
Wholesale Supply	0.00	0.00	0.00	0.00
Wholesale Export	-65.75	-90.29	-55.57	-80.23
Wholesale Import	0.00	0.00	0.00	0.00
Wholesale Import Supply	0.00	0.00	0.00	0.00
Slaughter Demand	0.00	0.00	0.00	0.00
Slaughter Supply	-6.35	-6.35	-6.14	-6.14
Farm Demand	0.00	0.00	0.00	0.00
Farm Supply	-0.01	-0.01	-0.01	-0.01
Pork				
Retail Demand	0.00	0.00	0.00	0.00
Retail Supply	0.00	0.00	0.00	0.00
Wholesale Demand	0.00	0.00	0.00	0.00
Wholesale Supply	0.00	0.00	0.00	0.00
Wholesale Export	-65.75	-90.29	-55.57	-80.23
Wholesale Import	0.00	0.00	0.00	0.00
Wholesale Import Supply	0.00	0.00	0.00	0.00
Slaughter Demand	0.00	0.00	0.00	0.00
Slaughter Supply	-0.11	-0.11	-0.03	-0.03
Slaughter Import Demand	0.00	0.00	0.00	0.00
Slaughter Import Supply	0.00	0.00	0.00	0.00
Lamb				
Retail Demand	0.00	0.00	0.00	0.00
Retail Supply	0.00	0.00	0.00	0.00
Retail Demand Import	0.00	0.00	0.00	0.00
Retail Supply Import	0.00	0.00	0.00	0.00
Wholesale Demand	0.00	0.00	0.00	0.00
Wholesale Supply	0.00	0.00	0.00	0.00
Slaughter Demand	0.00	0.00	0.00	0.00
Slaughter Supply	0.00	0.00	0.00	0.00
Farm Demand	0.00	0.00	0.00	0.00
Farm Supply	0.00	0.00	0.00	0.00
Poultry				
Retail Demand	0.00	0.00	0.00	0.00
Retail Supply	0.00	0.00	0.00	0.00
Retail Demand Export	0.00	0.00	0.00	0.00
Wholesale Demand	0.00	0.00	0.00	0.00
Wholesale Supply	0.00	0.00	0.00	0.00

[a] 1 & 5 herd scenarios assumes vaccinated animals are not stamped-out and the beef and pork export markets are closed for three months

[b] 1 & 5 herd scenarios assumes vaccinated animals are not stamped-out and the beef and pork export markets are closed for six months

Price and Quantity Effects

Using the exogenous supply shocks and export market closures, the percent change in price and quantity were calculated for seven scenarios. The first three scenarios follow the OIE Terrestrial Animal Code (article 8.5.8) which says the export markets may reopen three months after the last case is stamped-out or all vaccinated animals are destroyed. These scenarios include: (1) depopulation of known infected livestock (*No Vaccination)*; (2) depopulation of known infected and vaccinated livestock for *1 Herd* (*1 Herd-Depopulated*); and (3) depopulation of known infected and vaccinated livestock for *5 Herds* (*5 Herds-Depopulated*). The remaining four scenarios assume a depopulation of known infected livestock, but not depopulating the vaccinated livestock. These scenarios are designed to analyze the economic impacts when vaccinated livestock are not depopulated as the OIE guidelines suggest a longer export market ban. The OIE Terrestrial Animal Code (article 8.5.9) says when vaccinated animals are not depopulated; the export markets may reopen six months after the last vaccination is administered. These two scenarios are: (4) depopulation of known infected livestock, but not depopulating vaccinated livestock for *1 Herd* (*1 Herd-Not Depopulated Six Months*); and (5) depopulation of known infected livestock, but not depopulating vaccinated livestock for *5 Herds* (*5 Herds-Not Depopulated Six Months*). Because the export markets have opened faster than the suggested OIE guidelines in past FMD outbreaks (e.g., Netherlands in 2001), two additional scenarios evaluated the impacts of export markets opening before the suggested OIE guidelines (i.e., three months instead of the suggested six months): (6) depopulation of known infected livestock, but not depopulating vaccinated livestock for *1 Herd* (*1 Herd-Not Depopulated Three Months*); and (7) depopulation of known infected livestock, but not depopulating vaccinated livestock for *5 Herds* (*5 Herds-Not Depopulated Three Months*). .

Tables 6.7 – 6.9 contain the percentage change in price and quantities for *No Vaccination, 1 Herd-Depopulated and5 Herds-Depopulated* scenarios, and *1 Herd-Not Depopulated Three Months, 5 Herds-Not Depopulated Three Months, 1 Herd-Not Depopulated Six Months, 5 Herds-Not Depopulated Six Months* . Table 6.4, reports the percentage changes in prices and quantities for *No Vaccination* (the baseline scenario). In the *No Vaccination* scenario, the supply shock (number of animals stamped-out) is larger than the export demand shock (closure of the beef export markets), resulting in quantity at each marketing level to decline. Specifically, there is a supply shock at the feeder and fed cattle levels. This causes a shift to the left of the derived supply curves at the wholesale and retail levels. Simultaneously, there is a loss of the export market which results in an increase in supply of beef at the wholesale level. However, the supply shocks are larger than the demand shock resulting in a shift of the derived supply curves to the left. The decrease in quantity at the retail level leads to increased prices. While the retail level demands less beef from the wholesale level (shift of the derived demand curve at the wholesale level for beef to the left), the shift in the supply curve is larger than the shift in the derived demand curve, resulting in increased prices at the domestic wholesale level. The fed cattle market also sees an increase in price because the shift in the derived supply curve is larger than the shift in the derived demand curve. In addition to a decrease in the quantity of feeder cattle because of a supply shock, the demand for feeder cattle decreases quantity even more, resulting to a decline in the price of feeder cattle.

Imported and exported wholesale beef prices and quantities all decreased. This is expected as the price of wholesale beef falls fewer firms will import to the U.S.

The pork sector experiences an increase of quantity at the retail and wholesale levels while prices decline at both marketing levels. This occurs because the loss of the export markets shifts the derived supply curves to the right at both the retail and wholesale levels. Prices and quantities for exported and imported pork and domestic and imported slaughter hogs all decline. As the prices at the wholesale level fall due to the increase in wholesale level pork resulting from the loss of the export markets, importers supply less pork to the U.S. Additionally, as the derived demand for slaughter hogs declines, this results in lower prices and quantities at the domestic and import slaughter levels.

All lamb and poultry prices and quantities see small increases, except for export poultry. Because beef became relatively more expensive compared to pork, lamb, and poultry, we see increases in consumption of the other protein sources. With increased prices in poultry at the retail level, the United States will export less poultry.

Table 6.8 reports the changes in endogenous variables for the *1 Herd-Depopulated and5 Herds-Depopulated* scenarios. These scenarios assume the beef and pork export markets are closed for three months. Additionally, we assume there is no change in consumer demand. All percentage changes in prices and quantities have the same sign as *No Vaccination*. Additionally, the percentage change in prices and quantities for these two scenarios are slightly larger when compared to *No Vaccination*. Comparing *1 Herd-Depopulated* to *5 Herds-Depopulated*, the percentage changes in prices and quantities are slightly larger for *1 Herd-Depopulated* at each marketing level. The *1 Herd-Depopulated* scenario's prices and quantities are slightly larger because the length of outbreak is 35 days longer. This results in a longer ban on export markets and a 10% higher exogenous shift in export demand.

Table 6.9 reports the percentage changes in prices and quantities for *1 Herd-Not Depopulated Three Months*, *5 Herds-Not Depopulated Three Months, 1 Herd-Not Depopulated Six Months, 5 Herds-Not Depopulated Six Months*. By not destroying the vaccinated animals, this study follows the suggested OIE guidelines by closing the export markets six months after FMD is eradicated. Although the export demand shock is larger, the number of animals stamped-out is less. All four scenarios have the same sign and are similar in magnitude, except for export wholesale beef and pork quantities. The change in export wholesale beef quantity ranges from a decline of 59.1% (for *5 Herds-Not Depopulated Three Months* scenario) to 93.5% (for *1 Herd-Not Depopulated Six Months* scenario) while the export wholesale pork quantity ranges from a decline of 52.4% (for *5 Herds-Not Depopulated Three Months* scenario) to 84.9% (for *1 Herd-Not Depopulated Six Months* scenario).

Comparing the four *Not Depopulated* scenarios to the *No Vaccination* scenario, all signs are the same and the magnitude of changes in prices and quantities are similar, except for the exported wholesale quantity for the two scenarios with a six month export market ban. Specifically, the *1 Herd-Not Depopulated* scenarios have a longer length of outbreak by 44 days and have a slightly higher number of animals that are stamped-out. This results in slightly larger percentage changes in prices and quantities when comparing

1 Herd-Not Depopulated Three Months to *No Vaccination*. Closing the export markets an additional three months (*1 Herd-Not Depopulated Six Months*) results in slightly larger percentage changes in prices and quantities relative to *No Vaccination*. Because the length of outbreak and number of animals stamped-out in the *No Vaccination* and *5 Herds-Not Depopulated* scenarios are similar, the results are similar. The one exception is when the export markets are closed an additional three months. When the markets are closed an additional three months, the changes are slightly larger.

When comparing the *Depopulated* to the *Not Depopulated* scenarios, the changes in the endogenous variable are larger in the beef sector and similar for the pork, lamb, and poultry sectors for the *Depopulated* scenarios. This is expected because most of the vaccinated animals are cattle. As the vaccinated animals are removed, the supply shocks are larger.

Producer and Consumer Welfare

The changes in producer and consumer welfare for each commodity at the various marketing levels are reported in tables 6.10 – 6.12. The total change in producer surplus for the meat industry across all seven scenarios declines between $15.8 and $21.3 billion. Changes in total meat consumer surplus across the scenarios range from declines of $2.6 to $5.9 billion.

Table 6.10 reports the welfare impacts for *No Vaccination*. In this strategy, where only known infected livestock are depopulated and the export markets are closed for three months after the end of the outbreak, the producer surplus for each marketing level in the beef industry declines. The feeder cattle have the largest loss of $10,327.1 million.

Slaughter cattle, wholesale and retail beef decline by $4,287.8 million, $2,819.2, and $1,114.5 billion, respectively.

The pork, lamb and poultry industries gain producer surplus by $1,282.8 billion, $0.76 million and $1,078.8 million, respectively. With the exception of slaughter hogs, all sectors within the three species gain producer surplus. These gains are due to the combination of the export market closures, the very small FMD supply shock in swine and consumers substituting away from beef into the less expensive protein sources. The pork consumers benefit from closure of the pork export market and the relatively small supply shock. Although producers lose welfare, the losses are partially offset by consumers substituting away from beef to pork.

Total meat consumer surplus for *No Vaccination* strategy declines by $4,160.8 million (table 6.10). Beef consumers lose the most with a change in welfare of $6,219.34 million while domestic lamb, import lamb and poultry consumers lose $4.9, $18.8 and $60 million, respectively. Consumers of pork gain $2,037.8 million in consumer surplus.

Table 6.11 reports the welfare impacts for *1 Herd-Depopulated Three Months* and *5 Herds-Depopulated Three Months*. These strategies, where only known infected and vaccinated livestock are depopulated and the export markets are closed for three months after the end of the outbreak, exhibit declines in producer surplus at each marketing level declines as seen in the *No Vaccination* strategy. Feeder cattle again show the largest loss with $13,522.8 million for *1 Herd-Depopulated Three Months* and a loss of $12,681.6 million in producer surplus for *5 Herds-Depopulated Three Months* strategies. Slaughter cattle, wholesale and retail beef decline by $5,736.2, $3,979.5, and $1,617.3 million, respectively for 1 *Herd-Depopulated*. The producer surplus losses for the *5 Herds-Depopulated* strategy are slightly smaller, $5,248.3 million, $3,755.9 million, and $1,449.1 million for slaughter cattle, wholesale beef, and retail beef, respectively (table 6.8). The smaller producer welfare losses for the beef producers are a result of a higher number of livestock stamped-out and a longer trade ban. With the exception of slaughter hogs and import slaughter hogs, all sectors within the three species gain producer surplus.

The total meat consumer surplus results for the *1 Herd-Depopulated Three Months* and *5 Herds-Depopulated Three Months* strategies are similar; both decrease by by $5,818.18 million and $5,875.6, respectively (table 6.11). Beef consumers lose the most with a change in welfare of $8,297.1 million for *1 Herd-Depopulated* and $7,983.1 billion for *5 Herds-Depopulated.* For the *1 Herd-Depopulated* strategy, domestic lamb, import lamb and poultry consumers lose $8.4, $27.6 and $106.4 million, respectively, while domestic lamb, import lamb and poultry consumers lose $9.1, $28.9 and $106.1 million, respectively, in the *5 Herds-Depopulated* strategy. Consumers of pork gain $2,527.4 million and $2,197.2 million for the *1 Herd-Depopulated* and *5 Herds-Depopulated* strategies.

Table 6.12 reports the welfare impacts for *1 Herd-Not Depopulated Three Months, 5 Herds-Not Depopulated Three Months, 1 Herd-Not Depopulated Six Months,* and *5Herds-Not Depopulated six Months* scenarios. These strategies represent those where only known infected livestock will be depopulated (the vaccinated livestock are not depopulated in this scenario) and the export markets are closed for three and six months. The producer surplus for the *1 Herd-Not Depopulated Three Months* and *5*

Herds-Not Depopulated Three Months scenarios at each marketing level in the beef industry declines. Feeder cattle show the largest loss $11,202.9 and $10608.2 million for the *1 Herd-Not Depopulated Three Months* and *5 Herds-Not Depopulated Three Months* scenarios, respectively. Slaughter cattle, wholesale and retail beef for *1 Herd-Not Depopulated Three Months* scenario decline by $4,812.0, $2,942.2, $1, and 51.8, respectively. For the *5 Herds-Not Depopulated Three Months* scenarios, producer surplus declines by $4,434.3, $2,850.8, and $1,174.3 million for slaughter cattle, wholesale and retail beef, respectively. These changes in producer welfare for *5 Herds-Not Depopulated Three Months* are smaller because the number of animals stamped-out are smaller and the length of trade ban is shorter when compared to *1 Herd-Not Depopulated Three Months*.

All sectors for pork, lamb, and poultry see increases in producers welfare for the *1 Herd-Not Depopulated Three Months* and *5 Herds-Not Depopulated Three Months* scenarios, except for slaughter and import hogs (table 6.12). In the *1 Herd-Not Depopulated Three Months* scenario, the pork, lamb, and poultry sectors sees increases of $1,302.0 million, $67.1, and $1,037.5 million, respectively. The increases in producers surplus for pork, lamb, and poultry sectors for *5 Herds-Not Depopulated Three Months* are $1,267.3 million, $77.8, and $1,082.9 million, respectively.

Comparing the *1 Herd-Depopulated Three Months* to the *1 Herd-Not Depopulated Three Months* scenario, the difference in total beef producer surplus is $4,560.1 million. As expected, the *Not Depopulated* welfare losses are significantly smaller because the vaccinated animals were not destroyed. The differences in producer welfare for pork, lamb, and poultry are small and range from $0.16 to $464.9 million. The welfare gains for pork, lamb, and poultry in the *Not Depopulated* scenario are smaller when compared to the *Depopulated* scenario. This occurs because fewer consumers substitute out of beef into the other protein sources. When comparing *5 Herds-Depopulated Three Months* to the *5 Herds-Not Depopulated Three Months* scenario, the results are similar when comparing *1 Herd-Depopulated Three Months* to the *1 Herd-Not Depopulated Three Months* scenario, as discussed directly above.

The producer surplus for the *1 Herd-Not Depopulated Six Months* and *5 Herds-Not Depopulated Six Months* scenarios at each marketing level in the beef industry declines. For *1 Herd-Not Depopulated Six Month* scenario, feeder cattle slaughter cattle, wholesale beef and retail beef have producer welfare losses of $11,768.21, $ 5,368.5, $2,828.5, and $1,612.7 million, respectively. These welfare losses are similar to the *5 Herd-Not Depopulated Six Month* scenario. As noted earlier, the number of animals stamped-out is larger and length of the trade ban is longer for the *1 Herd* scenario. Thus, beef producer welfare losses are slightly larger for the *1 Herd-Not Depopulated Six Month* scenario. Similar to the *Three Months* scenarios, all sectors for pork, lamb, and poultry see increases in producers welfare for the *1 Herd-Not Depopulated Six Months* and *5 Herds-Not Depopulated Six Months* scenarios, except for slaughter and import hogs (table 6.12).

Comparing the *1 Herd-Not Depopulated Three Months* to the *1 Herd-Not Depopulated Six Months* scenario, the difference in total beef producer surplus is $1,441.5 million. As expected, the welfare losses in the *Six Months* scenario are larger because the loss of the beef and pork export markets is three months longer. The differences in producer welfare for pork, lamb, and poultry are small and range from $0.08 to $338.0 million. As expected, the welfare gains for pork, lamb, and poultry in the *Six Months* scenario are smaller when compared to the *Three Months* scenario. When comparing *5 Herds-Not Depopulated Three Months* to the *5 Herds-Not Depopulated Six Months* scenario, the results are similar when comparing *1 Herd-Not Depopulated Three Months* to the *1 Herd-Not Depopulated Six Months* scenario, as discussed directly above.

Total meat consumer surplus for *1 Herd-Not Depopulated Three Months, 5 Herds-Not Depopulated Three Months*, *5 Herds-Not Depopulated Three Months, and 5Herds-Not Depopulated Six Months* scenarios are similar with consumer surplus declining by $2,681.8 to $4,152.4 million. Similar to the *Depopulated* scenarios, beef consumers lose the most with a change in welfare of $5,815.2 to $6,410.7 million. The change in beef consumer welfare for the *Not Depopulated* scenarios is smaller when compared to the *Depopulated* scenarios. This is a result of the larger supply shocks in the *Depopulated* scenarios. Changes in consumer surplus for pork, domestic lamb, imported lamb, and poultry are similar across both *Depopulated* and *Not Depopulated* scenarios. .

The results discussed above and presented in the tables below demonstrate the importance vaccine strategies can have on the U.S. meat and livestock markets. As the number of animals stamped-out increased (comparing *Depopulated* to *Not Depopulated* scenarios), so did the welfare losses to the beef industry. The welfare losses in the beef industry impacted the other protein markets. Specifically, the gains in the other protein markets were smaller. Although the length of the export market ban impacted the producer welfare measures, the impacts were smaller than comparing the *Depopulated* and *Not Depopulated* scenarios. Similarly, the changes in consumer welfare were smaller when looking at the length of the trade ban (*Three Months* to the *Six Months* scenarios) compared to the depopulation of vaccinated animals (*Depopulated* to the *Not Depopulated* scenarios).

Table 6.7. Percentage Changes in the Endogenous Variables for *No Vaccination* Assuming Export Market Closure of Three Months[a]

Endogenous Variables	*No Vaccination*
Beef Sector:	
Retail Beef Price	7.77*
Retail Beef Quantity	-5.68*
Wholesale Beef Price	7.17*
Wholesale Beef Quantity	-8.47*
Exported Wholesale Beef Quantity	-56.69*
Wholesale Beef Import Price	-4.28*
Wholesale Beef Import Quantity	-3.08*
Fed Cattle Price	4.66*
Fed Cattle Quantity	-13.12*
Feeder Cattle Price	-38.72*
Feeder Cattle Quantity	-8.53*
Pork Sector:	
Retail Pork Price	-3.37*
Retail Pork Quantity	3.44*
Wholesale Pork Price	-4.14*
Wholesale Pork Quantity	6.07*
Exported Wholesale Pork Quantity	-50.25*
Wholesale Pork Import Price	-2.22*
Wholesale Pork Import Quantity	-3.08*
Slaughter Hog Price	-4.53*
Slaughter Hog Quantity	-1.85*
Import Slaughter Hog Price	-0.72*
Import Slaughter Hog Quantity	-1.24*
Lamb Sector:	
Retail Lamb Price	2.97*
Retail Lamb Quantity	0.85*
Import Retail Lamb Price	4.59*
Import Retail Lamb Quantity	0.86*
Wholesale Lamb Price	1.07*
Wholesale Lamb Quantity	0.36*
Slaughter Lamb Price	0.64*
Slaughter Lamb Quantity	0.14*
Feeder Lamb Price	0.48*
Feeder Lamb Quantity	0.05*
Poultry Sector:	
Retail Poultry Price	1.48*
Retail Poultry Quantity	0.54*
Exported Retail Poultry Quantity	-0.79*
Wholesale Poultry Price	0.70*
Wholesale Poultry Quantity	0.09*

*Indicates the estimates were significantly different at the 0.05 level.[a] No change in consumer demand.

Table 6.8. Percentage Changes in the Endogenous Variables for *1 Herd-Depopulated* and *5 Herds-Depopulated* Assuming Export Market Closure of Three Months[a]

Endogenous Variables	*1 Herd-Depopulated* *Three Months*	*5 Herds-Depopulated* *Three Months*
Beef Sector:		
Retail Beef Price	10.64*	10.34*
Retail Beef Quantity	-7.63*	-7.27*
Wholesale Beef Price	9.50*	9.11*
Wholesale Beef Quantity	-11.37*	-10.91*
Exported Wholesale Beef Quantity	-70.47*	-60.12*
Wholesale Beef Import Price	-5.55*	-5.11*
Wholesale Beef Import Quantity	-3.86*	-3.16*
Fed Cattle Price	6.11*	6.06*
Fed Cattle Quantity	-17.29*	-16.17*
Feeder Cattle Price	-51.27*	-47.85*
Feeder Cattle Quantity	-11.26*	-10.51*
Pork Sector:		
Retail Pork Price	-4.10*	-3.41*
Retail Pork Quantity	4.41*	3.91*
Wholesale Pork Price	-5.02*	-4.21*
Wholesale Pork Quantity	7.47*	6.47*
Exported Wholesale Pork Quantity	-62.22*	-52.64*
Wholesale Pork Import Price	-2.78*	-2.27*
Wholesale Pork Import Quantity	-3.86*	-3.16*
Slaughter Hog Price	-5.18*	-4.37*
Slaughter Hog Quantity	-2.36*	-1.83*
Import Slaughter Hog Price	-0.98*	-0.75*
Import Slaughter Hog Quantity	-1.59*	-1.23*
Lamb Sector:		
Retail Lamb Price	4.80*	5.01*
Retail Lamb Quantity	1.27*	1.35*
Import Retail Lamb Price	7.15*	7.42*
Import Retail Lamb Quantity	1.30*	1.38*
Wholesale Lamb Price	1.66*	1.77*
Wholesale Lamb Quantity	0.53*	0.56*
Slaughter Lamb Price	0.95*	0.99*
Slaughter Lamb Quantity	0.21*	0.22*
Feeder Lamb Price	0.68*	0.71*
Feeder Lamb Quantity	0.08*	0.09*
Poultry Sector:		
Retail Poultry Price	2.22*	2.22*
Retail Poultry Quantity	0.81*	0.80*
Exported Retail Poultry Quantity	-1.10*	-1.09*
Wholesale Poultry Price	1.03*	1.03*
Wholesale Poultry Quantity	0.14*	0.14*

* Indicates the estimates were significantly different at the 0.05 level.
[a] No change in consumer demand.

Table 6.9. Percentage Changes in the Endogenous Variables for *1 Herd-Not Depopulated* and *5 Herds-Not Depopulated* Assuming Export Market Closure of Three and Six Months.[a]

Endogenous Variables	*1 Herd-Not Depopulated Three Months*	*1 Herd-Not Depopulated Six Months*	*5 Herds-Not Depopulated Three Months*	*5 Herds-Not Depopulated Six Months*
Beef Sector:				
Retail Beef Price	8.00*	6.72*	7.83*	6.77*
Retail Beef Quantity	-5.98*	-5.76*	-5.78*	-5.62*
Wholesale Beef Price	7.16*	6.35*	7.06*	6.36*
Wholesale Beef Quantity	-8.80*	-8.14*	-8.59*	-8.01*
Exported Wholesale Beef Quantity	-69.42*	-93.47*	-59.10*	-83.40*
Wholesale Beef Import Price	-4.72*	-5.26*	-4.37*	-4.92*
Wholesale Beef Import Quantity	-3.98*	-5.63*	-3.27*	-4.94*
Fed Cattle Price	4.06*	2.97*	4.40*	3.21*
Fed Cattle Quantity	-14.12*	-14.88*	-13.36*	-14.17*
Feeder Cattle Price	-42.10*	-44.41*	-39.79*	-42.22*
Feeder Cattle Quantity	-9.23*	-9.75*	-8.69*	-9.25*
Pork Sector:				
Retail Pork Price	-4.36*	-6.24*	-3.61*	-5.53*
Retail Pork Quantity	4.04*	5.03*	3.63*	4.60*
Wholesale Pork Price	-5.30*	-7.69*	-4.43*	-6.79*
Wholesale Pork Quantity	7.39*	9.80*	6.35*	8.83*
Exported Wholesale Pork Quantity	-61.98*	-84.85*	-52.42*	-75.42*
Wholesale Pork Import Price	-2.84*	-4.07*	-2.33*	-3.57*
Wholesale Pork Import Quantity	-3.98*	-5.63*	-3.27*	-4.94*
Slaughter Hog Price	-5.48*	-7.84*	-4.54*	-6.95*
Slaughter Hog Quantity	-2.30*	-3.26*	-1.86*	-2.81*
Import Slaughter Hog Price	-0.95*	-1.33*	-0.77*	-1.14*
Import Slaughter Hog Quantity	-1.55*	-2.15*	-1.24*	-1.86*

*Indicates the estimates were significantly different at the 0.05 level.

[a]**No change in consumer demand**

Table 6.9. Percentage Changes in the Endogenous Variables for *1 Herd-Not Depopulated* and *5 Herds-Not Depopulated* Assuming Export Market Closure of Three and Six Months, Continued.[a]

Endogenous Variables	*1 Herd-Not Depopulated Three Months*	*1 Herd-Not Depopulated Six Months*	*5 Herds-Not Depopulated Three Months*	*5 Herds-Not Depopulated Six Months*
Lamb Sector:				
Retail Lamb Price	2.78*	0.82*	3.19*	1.19*
Retail Lamb Quantity	0.72*	0.22*	0.85*	0.32*
Import Retail Lamb Price	4.18*	1.17*	4.83*	1.98*
Import Retail Lamb Quantity	0.78*	0.21*	0.87*	0.34*
Wholesale Lamb Price	1.01*	0.27*	1.13*	0.41*
Wholesale Lamb Quantity	0.32*	0.09*	0.34*	0.13*
Slaughter Lamb Price	0.55*	0.15*	0.63*	0.24*
Slaughter Lamb Quantity	0.12*	0.03*	0.13*	0.05*
Feeder Lamb Price	0.39*	0.10*	0.44*	0.16*
Feeder Lamb Quantity	0.05*	0.01*	0.05*	0.02*
Poultry Sector:				
Retail Poultry Price	1.54*	1.09*	1.61*	1.16*
Retail Poultry Quantity	0.55*	0.39*	0.58*	0.42*
Exported Retail Poultry Quantity	-0.76*	-0.55*	-0.79*	-0.59*
Wholesale Poultry Price	0.69*	0.52*	0.74*	0.55*
Wholesale Poultry Quantity	0.09*	0.07*	0.10*	0.08*

*Indicates the estimates were significantly different at the 0.05 level.

[a]No change in consumer demand.

Table 6.10. Changes in Producer and Consumer Surplus for *No Vaccination* Assuming Export Market Closure of Three Months[a]

Industry/Market Level	million $
Producer Surplus	
Retail Beef	-1,114.50*
Wholesale Beef	-2,819.23*
Slaughter Cattle	-4,287.80*
Feeder Cattle	-10,327.11*
Total Beef Producer Surplus	-18,382.90*
Retail Pork	1,026.78*
Wholesale Pork	997.54*
Slaughter Hog	-662.63*
Imported Slaughter Hog	-18.79*
Total Pork Producer Surplus	1,282.79*
Retail Domestic Lamb	34.53*
Retail Imported Lamb	28.08*
Wholesale Lamb	5.50*
Slaughter Lamb	2.59*
Feeder Lamb	1.45*
Total Lamb Producer Surplus	75.76*
Retail Poultry	1,078.61*
Wholesale Poultry	0.34*
Total Poultry Producer Surplus	1,078.84*
Total Meat Producer Surplus	**-15,810.59***
Consumer Surplus	
Retail Beef	-6,219.34*
Retail Pork	2,037.78*
Retail Domestic Lamb	-4.89*
Retail Imported Lamb	-18.80*
Retail Poultry	-59.96*
Total Meat Consumer Surplus	**-4,160.81***

*Indicates the estimates were significantly different at the 0.05 level.
[a]No change in consumer demand.

Table 6.11. Changes in Producer and Consumer Surplus for *1 Herd-Depopulated* and *5 Herds-Depopulated* Assuming Export Market Closure of Three Months[a]

Industry/Market Level	million $	
Producer Surplus	*1 Herd-Depopulated*	*5 Herds-Depopulated*
Retail Beef	-1,617.31*	-1,449.14*
Wholesale Beef	-3,979.48*	-3,755.92*
Slaughter Cattle	-5,736.22*	-5,248.34*
Feeder Cattle	-13,522.78*	-12,681.63*
Total Beef Producer Surplus	-24,706.52*	-22,926.45*
Retail Pork	1,308.72*	1,203.98*
Wholesale Pork	1,230.05*	1,107.81*
Slaughter Hog	-791.20*	-648.53*
Imported Slaughter Hog	-0.89*	-0.69*
Total Pork Producer Surplus	1,554.81*	1,536.05*
Retail Domestic Lamb	53.27*	55.56*
Retail Imported Lamb	42.85*	44.72*
Wholesale Lamb	8.40*	8.94*
Slaughter Lamb	3.74*	3.94*
Feeder Lamb	2.02*	2.13*
Total Lamb Producer Surplus	118.38*	123.59*
Retail Poultry	1,502.19*	1,504.30*
Wholesale Poultry	0.49*	0.49*
Total Poultry Producer Surplus	1,502.76*	1,504.84*
Total Meat Producer Surplus	**-21,324.94***	**-19,636.14***
Consumer Surplus		
Retail Beef	-8,297.07*	-7,983.14*
Retail Pork	2,527.35*	2,197.15*
Retail Domestic Lamb	-8.36*	-9.10*
Retail Imported Lamb	-27.65*	-28.88*
Retail Poultry	-106.44*	-106.13*
Total Meat Consumer Surplus	**-5,818.06***	**-5,875.62***

*Indicates the estimates were significantly different at the 0.05 level.

[a]No change in consumer demand.

Table 6.12. Changes in Producer and Consumer Surplus for *1 Herd-Not Depopulated* and *5 Herds-Not Depopulated* Assuming Export Market Closure of Three and Six Months[a]

	million $			
Industry/Market Level	*1 Herd-Not Depopulated Three Months*	*1 Herd-Not Depopulated Six Months*	*5 Herds-Not Depopulated Three Months*	*5 Herds-Not Depopulated Six Months*
Producer Surplus				
Retail Beef	-1,351.79*	-1,612.70*	-1,174.27*	-1,509.81*
Wholesale Beef	-2,942.24*	-2,828.52*	-2,850.78*	-2,728.99*
Slaughter Cattle	-4,812.00*	-5,368.47*	-4,434.29*	-5,018.61*
Feeder Cattle	-11,202.86*	-11,768.09*	-10,608.17*	-11,237.72*
Total Beef Producer Surplus	-20,146.38*	-21,587.90*	-18,955.32*	-20,528.26*
Retail Pork	1,133.49*	1,233.63*	1,051.11*	1,171.30*
Wholesale Pork	1,150.96*	1,329.32*	1,024.43*	1,244.52*
Slaughter Hog	-809.57*	-1,147.60*	-662.41*	-1,010.85*
Imported Slaughter Hog	-0.87*	-1.21*	-0.70*	-1.04*
Total Pork Producer Surplus	1,301.99*	1,174.98*	1,267.26*	1,182.91*
Retail Domestic Lamb	32.50*	9.51*	35.80*	13.60*
Retail Imported Lamb	24.82*	6.99*	28.96*	11.84*
Wholesale Lamb	5.21*	1.37*	5.58*	2.08*
Slaughter Lamb	2.15*	0.60*	2.52*	0.91*
Feeder Lamb	1.18*	0.30*	1.31*	0.47*
Total Lamb Producer Surplus	67.13*	20.06*	77.79*	30.69*
Retail Poultry	1,037.30*	767.23*	1,082.50*	809.69*
Wholesale Poultry	0.33*	0.25*	0.35*	0.26*
Total Poultry Producer Surplus	1,037.51*	767.64*	1,082.89*	809.92*
Total Meat Producer Surplus	**-17,634.45***	**-19,714.51***	**-16,421.92***	**-18,443.25***
Consumer Surplus				
Retail Beef	-6,410.68*	-5,815.24*	-6,272.27*	-5,794.11*
Retail Pork	2,487.71*	3,281.06*	2,131.11*	2,948.71*
Retail Domestic Lamb	-4.55*	-1.06*	-5.23*	-1.84*
Retail Imported Lamb	-15.70*	-4.34*	-18.34*	-6.68*
Retail Poultry	-61.75*	-40.40*	-73.38*	-48.28*
Total Meat Consumer Surplus	**-3,956.98***	**-2,581.78***	**-4,152.42***	**-2,869.03***

* Indicates the estimates were significantly different at the 0.05 level.

[a] No change in consumer demand.

Chapter 7 – Discussion and Conclusions

Foot-and-mouth disease outbreaks throughout the world have demonstrated the catastrophic economic effects that FMD can have on a country. Combining the numerous FMD outbreaks throughout the world in the past several years with the increased globalization, including international travel and trade, risk of transmission of FMD to the U.S. is increasing. This study poses several scenarios of how such an outbreak may impact the industry and consumers of the livestock industry.

In 2007, Kansas cattlemen and beef producers accounted for over 22% of the U.S. beef supply. The livestock industry accounted for nearly 63% of the Kansas income (Kansas Agricultural Statistics, 2009). An outbreak of FMD in this region would not only have a devastating effect on the state of Kansas, but would be felt throughout the United States and world markets.

Recently, the USDA released an animal health directive, *VS 2015*. The intent of *VS 2015* is for the U.S. to implement better preventative practices and become better prepared for a contagious animal disease outbreak. The main objective of this research is to determine and understand the possible changes in producer and consumer welfare due to various management strategies of an FMD outbreak in southwest Kansas. In particular, this thesis investigated the impacts of alternative FMD vaccination strategies. As an empirical approach to this objective, the use of an epidemiological disease spread model and a multi-market equilibrium displacement model are used to analyze the impacts of a FMD outbreak.

The epidemiological output scenarios included: (1) destruction of known infected herds only without vaccination (*No Vaccination)*; (2) 3 km ring vaccination after 1 herd has been detected (*1 Herd Detected 3 km Vaccination Ring*); and (3) 3 km ring vaccination after 5 infected herds have become detected (*5 Herds Detected 3 km Vaccination Ring)*. The total number of animals destroyed was approximately 2.1 million head across the three scenarios. The number of animals vaccinated for the *1 Herd and 5 Herds* scenarios ranged from 598,355 to 839,018 head. The length of the outbreak lasted between 103 to 148 days. This output provides U.S. policy makers with valuable information that can assist in determining which control strategy to use in a FMD outbreak in a dense cattle feeding region.

The epidemiological results from this research have similar findings with past research. Pendell (2007) investigated the impacts of alternate traceability levels using the same region as this study. He found the average number of animals stamped-out by production type to be lower and some minor differences between the alternate control strategies. However, the duration of the outbreak was similar to this study and the average duration varied little between the strategies. Paarlberg et al. (2008) looked at a region in the Midwest that was heavily populated with swine. Although the mean number of animals stamped-out by scenario was significantly lower, the average number of animals stamped-out and duration of the outbreak between strategies was similar. Using a different geographic region, Zhao, Wahl, and Marsh (2006) found there were little differences across strategies in the percent of inventory that was depopulated using ring vaccination.

Several limitations with this study exist in regards to the epidemiological modeling. It is assumed that FMD is only allowed spread within the 14 counties in southwest Kansas. Because FMD was only allowed to spread within the 14 counties, the number of animals stamped-out and the duration of the outbreak could be underestimated. Additionally, it is assumed that only three herds per day would be stamped-out. Although this was beyond the scope of the study, additional resources would all more herds to be destroyed, which could alter the spread of the disease. The origin of the infection occurred in a medium size feedlot. Pendell et al. (2007) has shown that the index herd can have significant impacts on the epidemiological results.

Welfare results differed by scenario. The total change in producer surplus for the meat industry across all scenarios declined between $15,810.6 and $21324.9 million. *No Vaccination* had the smallest decline in total meat producer surplus with $15,810.6 million. The scenarios that depopulated the vaccinated animals had larger welfare losses (by approximately $4,000 million) when compared to the scenarios that did not depopulate vaccinated animals. This was a result of larger supply shocks. As expected, the scenarios with longer trade bans had larger total producer welfare losses (by approximately $2,000 million). Changes in consumer surplus across the scenarios range from declines of $2,581.8 to $5,875.6 million. Beef, lamb, and poultry all experienced declines in consumer welfare while pork consumers experience an increase in welfare.

While the economic model presented here is an improvement over past studies, some limitations still exist. Although past research has found there are small changes in consumer demand regarding food safety events, it is assumed there would be no change in consumer demand because FMD does not affect humans. This limitation could easily be addressed by allowing changes in consumer demand. Additionally, past empirical evidence suggests there is no set standard length of ban on export markets from countries with FMD outbreaks. Past experiences has shown the trade bans for some outbreaks to be shorter than the OIE's suggested guidelines (the Netherlands in 2001) while others are much longer (the UK in 2001). This study followed the OIE's suggested guidelines.

The economic impacts found in this research are within the range of past studies. This study found total change in surplus (producer and consumer) for the meat industry across all scenarios decreased between $19,971 and $27,143 million. Zaho, Whal, and Marsh (2006) investigated the impacts of FMD with improvements in traceability and alternate ring vaccination scenarios. They found changes in total ranging from losses of $18.5 billion to losses of $266 billion. Pendell et al. (2006) studied the impacts of different disease introduction scenarios. Using a partial equilibrium model, they estimated changes in total surplus ranging from a decline of $28 million to a decline of $590 million.

The value of this research is its ability to demonstrate and quantify the economic effects that alternative vaccination strategies can have on a FMD outbreak in southwest Kansas. Vaccination for FMD has enormous international trade implications, which make these results extremely important to a number of governmental agencies, state and local animal health officials, and the livestock and related industries. Future research of alternative vaccination strategies could further this research by increasing the size of the study region and investigating additional control strategies (e.g., length of time that elapses before vaccination begins and combinations of vaccination and depopulation strategies). Moreover, the standard deviations for the number of animals stamped-out are fairly large. Future research could investigate the entire distribution of epidemiological and economic results, instead of the expected value, as done in this research and past research.

Overall, this study increases our understanding of the impacts of alternate vaccination strategies in the event of a FMD outbreak in a highly dense cattle feeding region. A simulated multi-market displacement model was used in conjunction with an animal disease spread model to quantity these effects. The findings show that as we use vaccination strategies, changes in producer welfare losses are larger. This is especially true when vaccinated animals are destroyed and when the length of trade bans are longer.

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Appendix A- Epidemiology Input Parameters

The epidemiological model used in this research is the North American Animal Disease Spread (NAADSM) version 3.1.22. The production types for this research include: Beef Feedlot, Cow-Calf, Swine, Dairy, and Lamb. The following parameters were provided by Premashthira (2009).

Input Parameters

The key disease parameters are as follows:

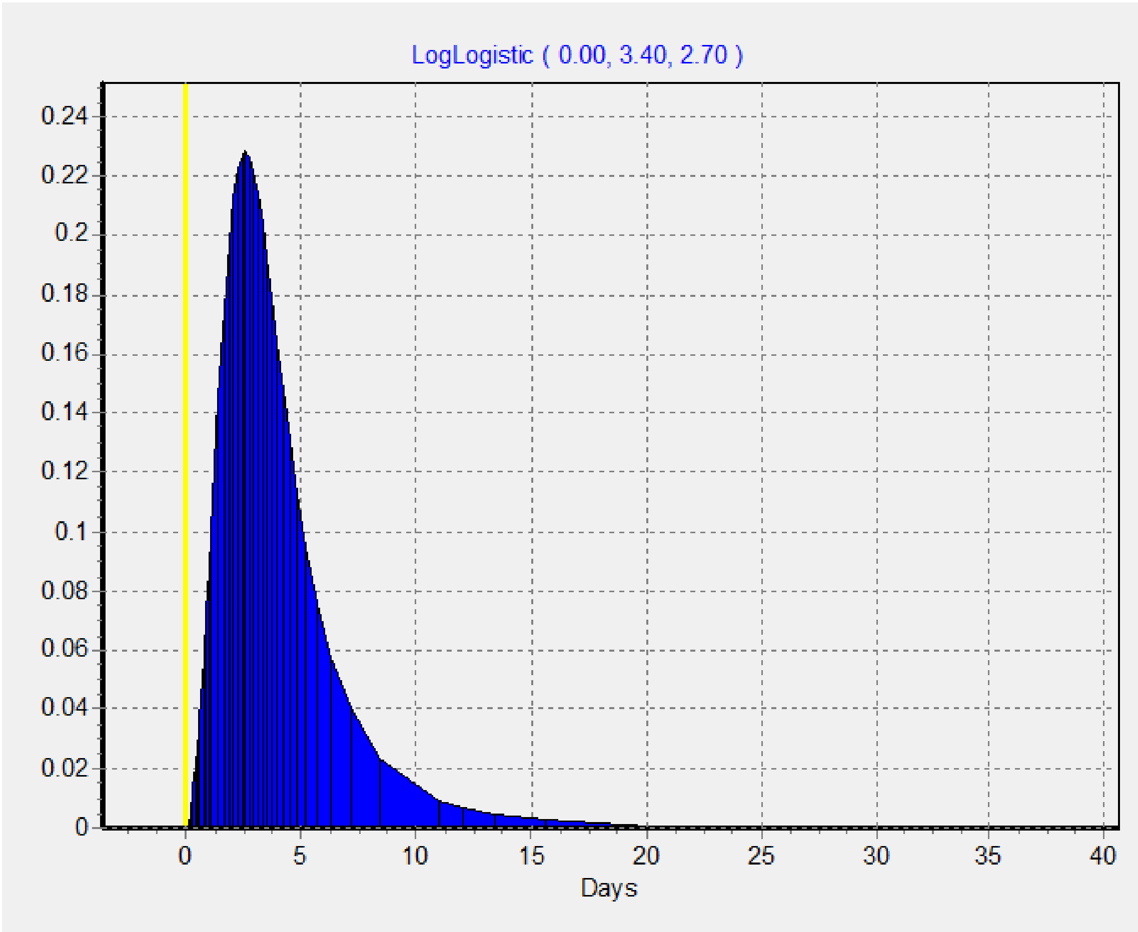

Figure A.1. Defining the Duration of the *Latent* Period for Cattle

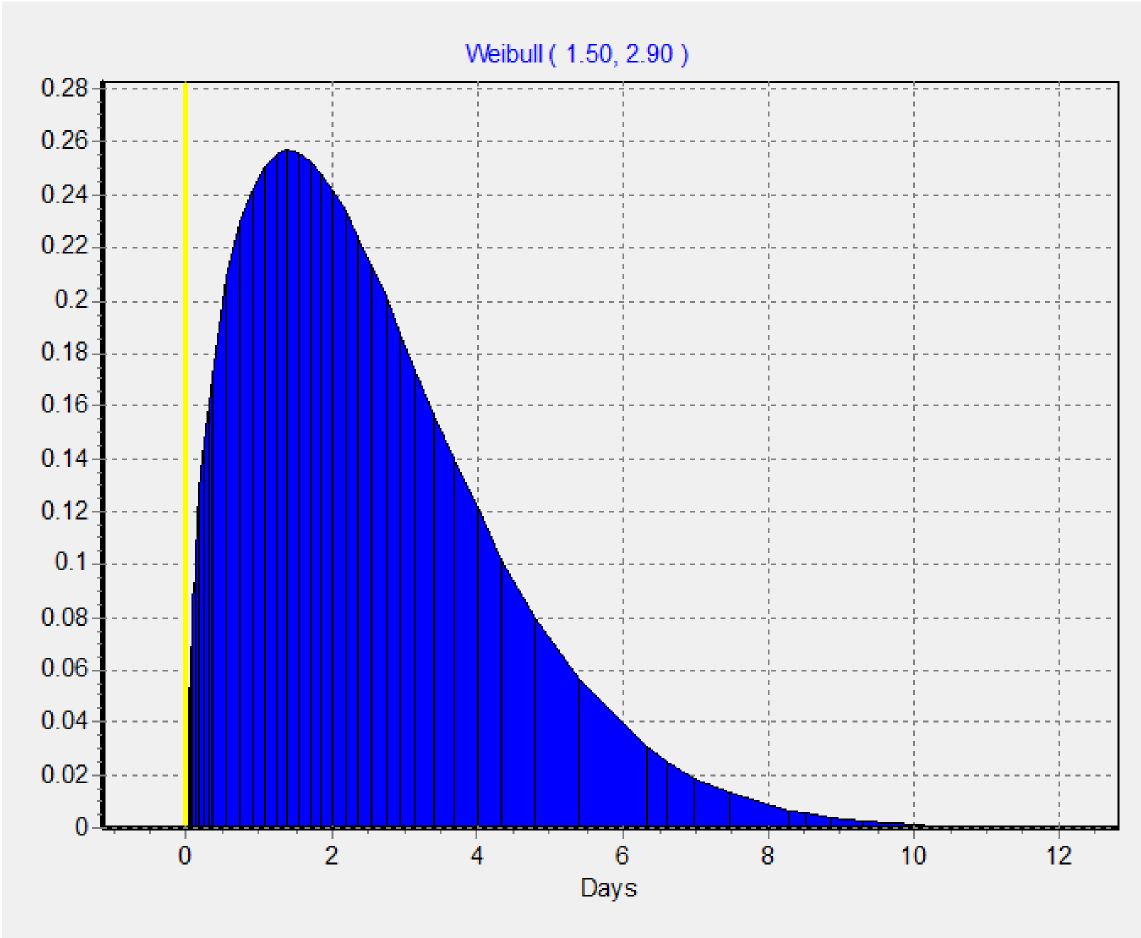

Figure A.2. Defining the Duration of the *Latent* Period for Swine

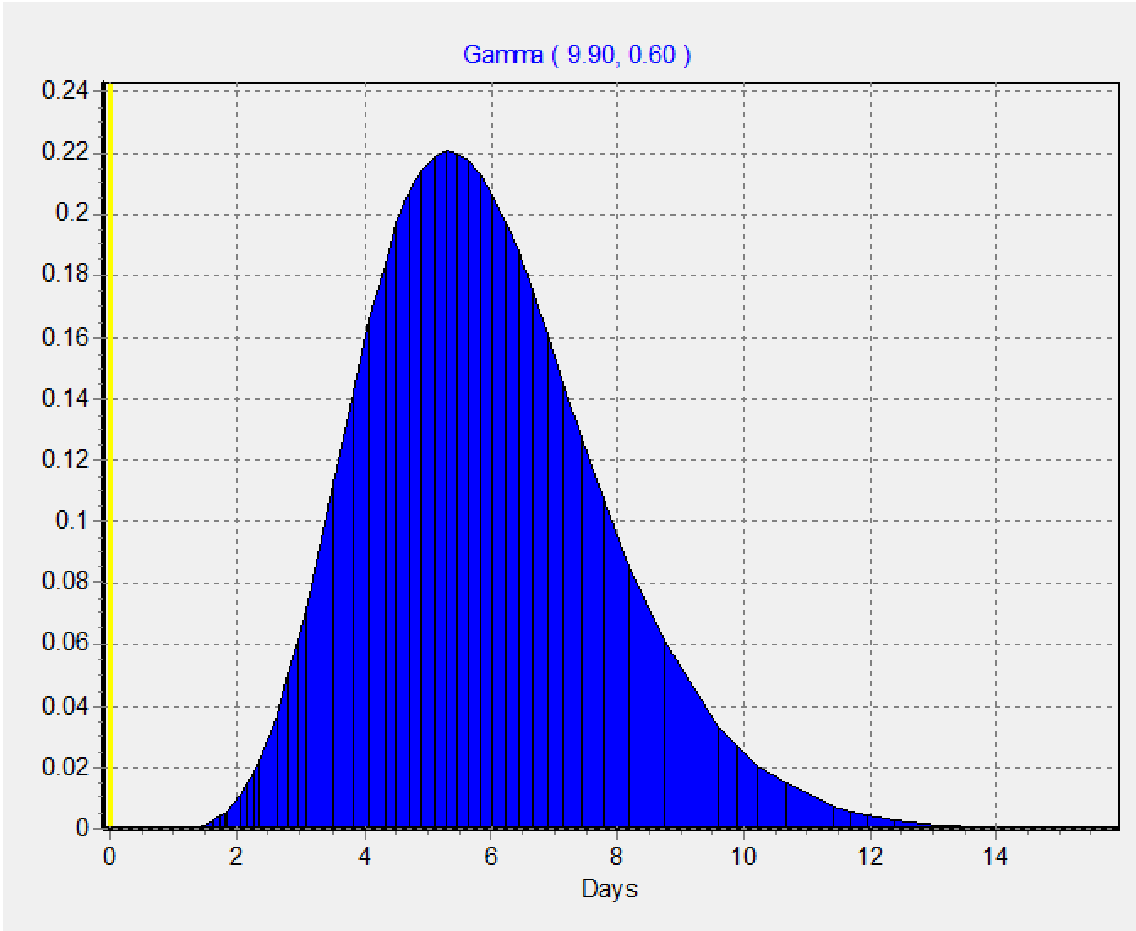

Figure A.3 Defining the Duration of the *Latent* Period for Sheep

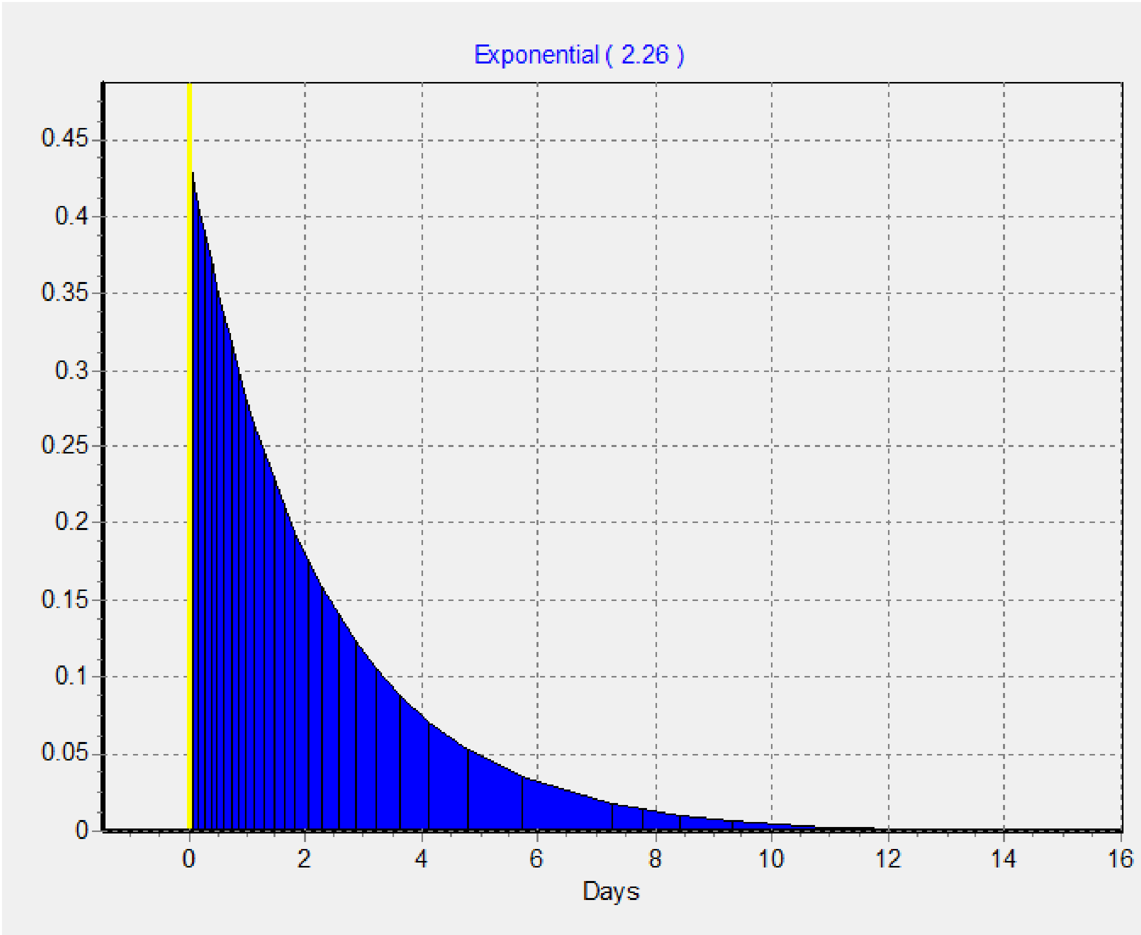

Figure A.4 Defining the Duration of the *Infectious Subclinical* Period for Cattle

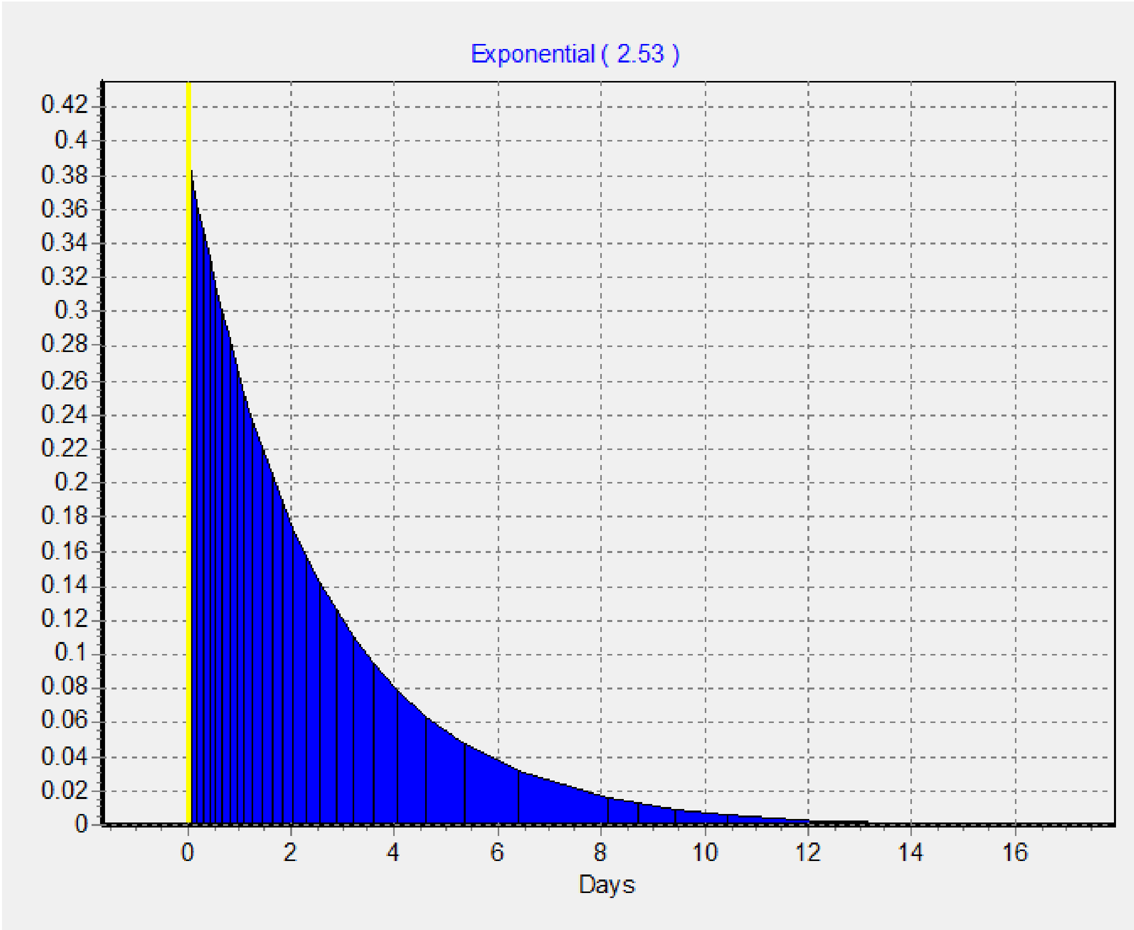

Figure A.5 Defining the Duration of the *Infectious Subclinical* Period for Swine

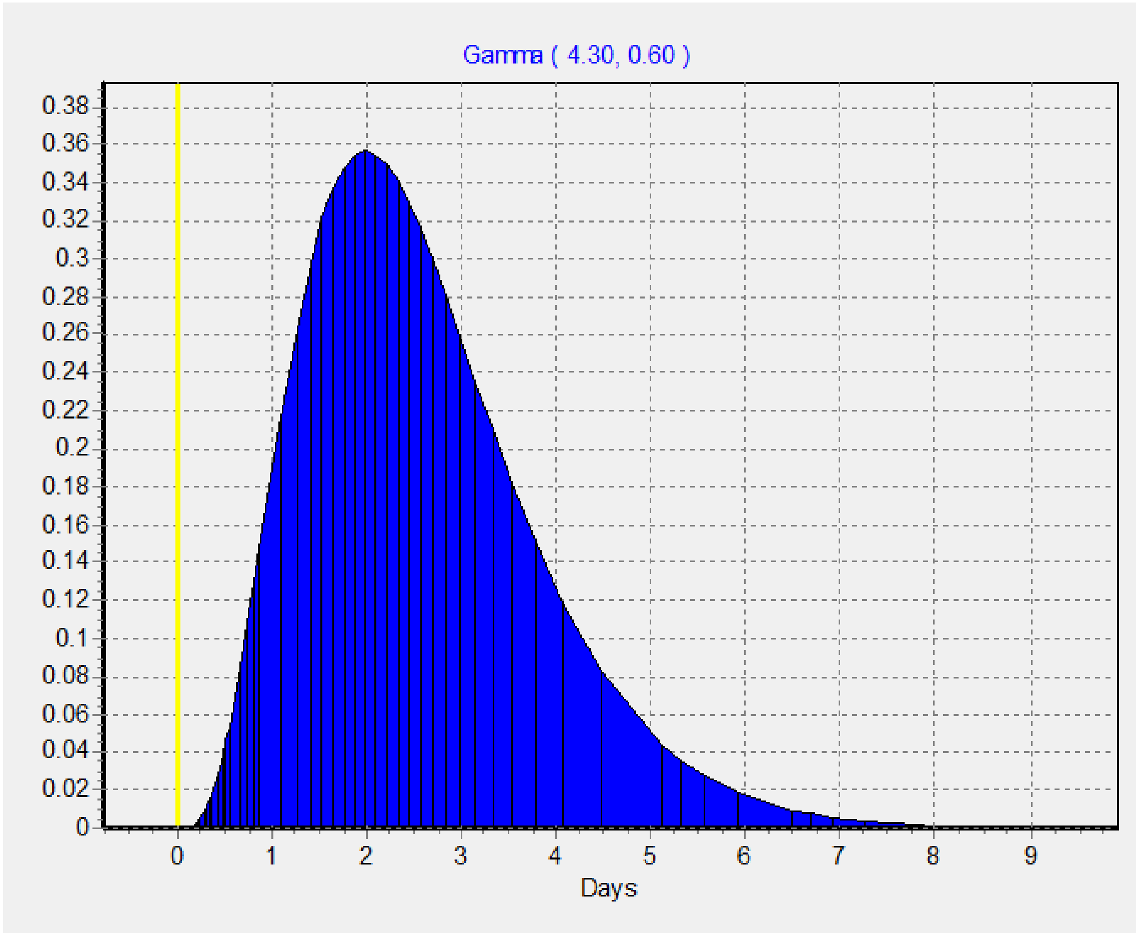

Figure A.6 Defining the Duration of the *Infectious Subclinical* Period for Lamb

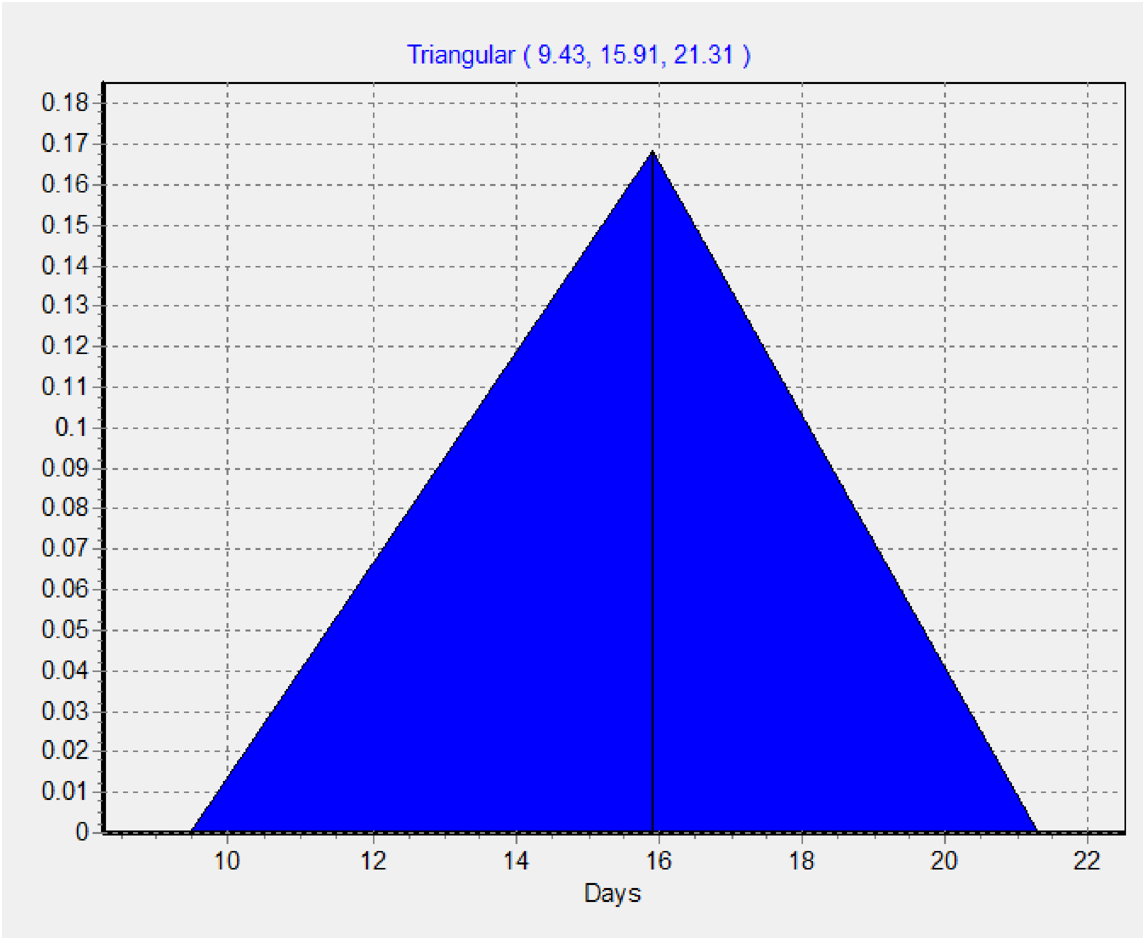

Figure A.7 Defining the Duration of the *Infectious Clinical* Period for Cattle

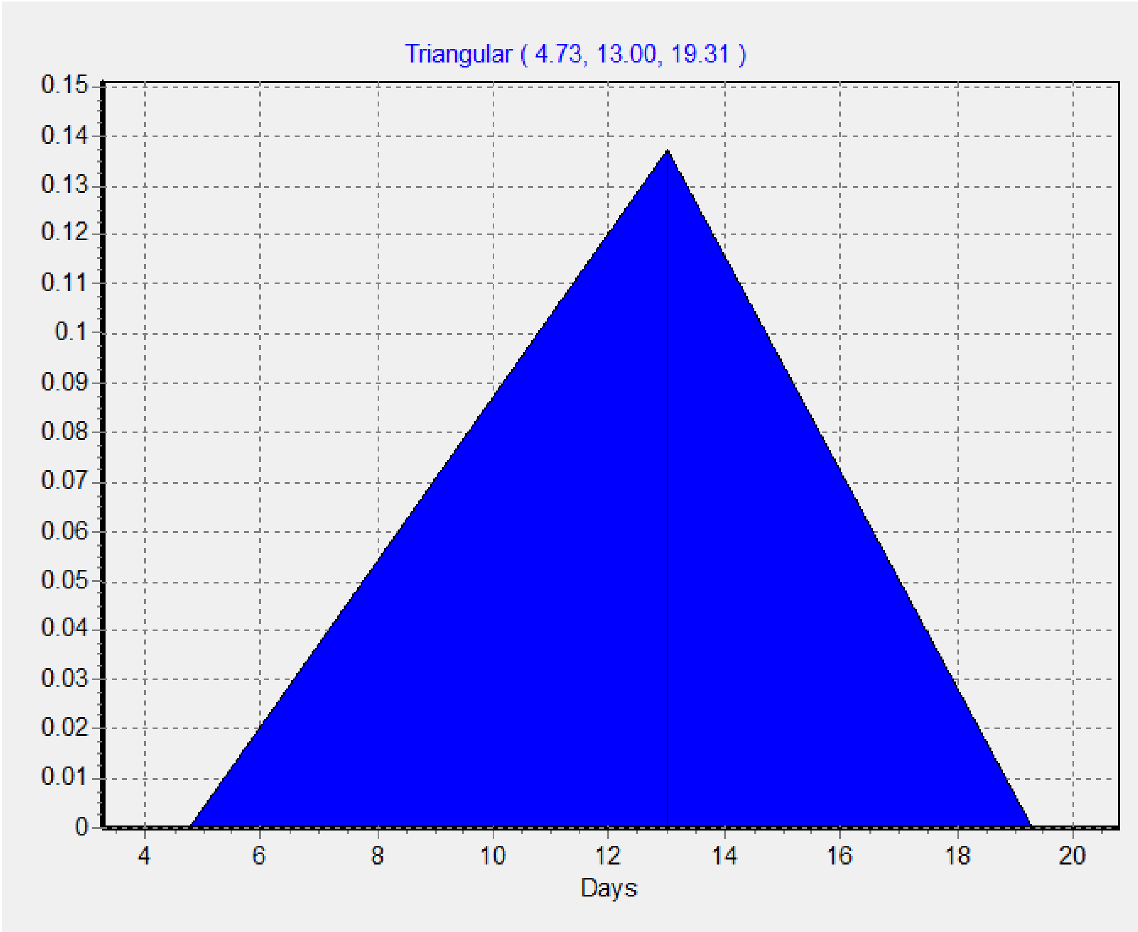

Figure A.8 Defining the Duration of the *Infectious Clinical* Period for Swine

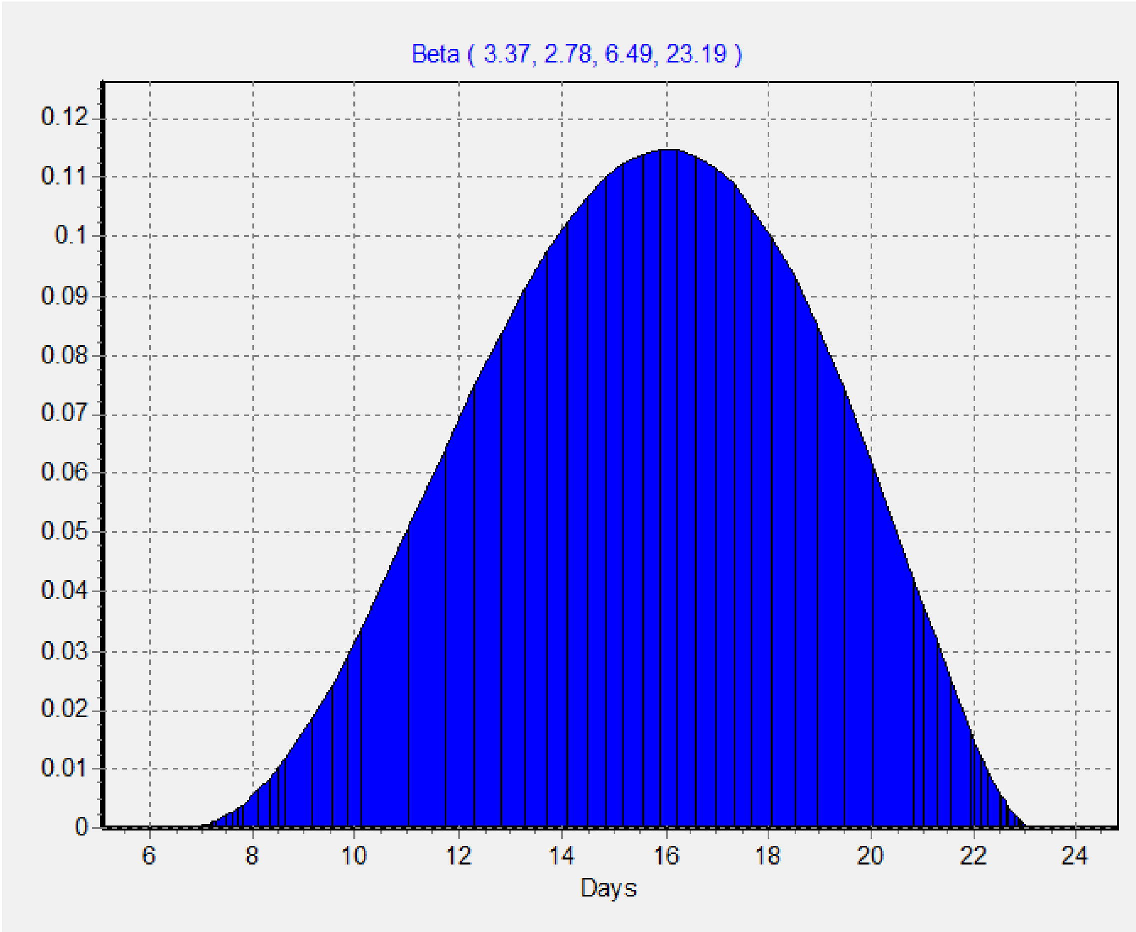

Figure A.9 Defining the Duration of the *Infectious Clinical* Period for Lamb

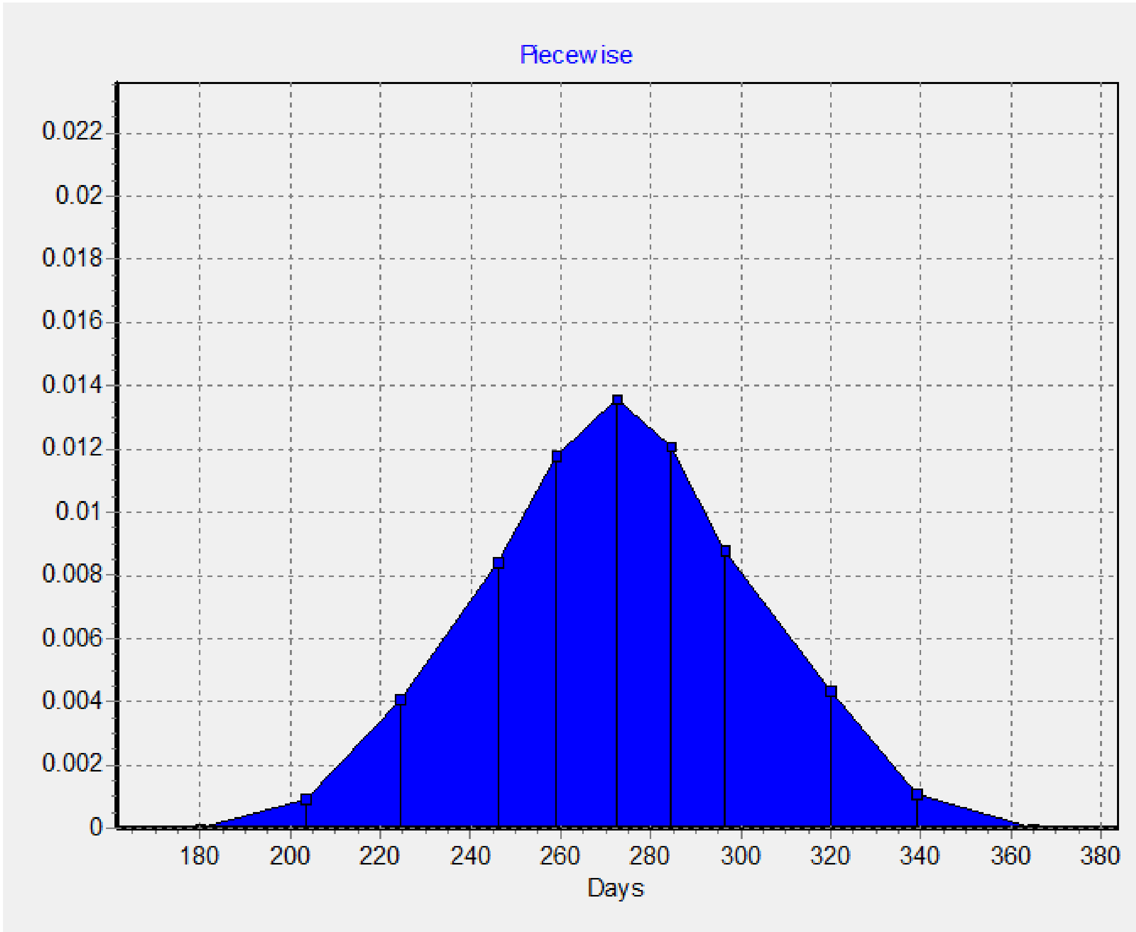

Figure A.10 Defining the Duration of the *Immune* Period for Cattle and Swine

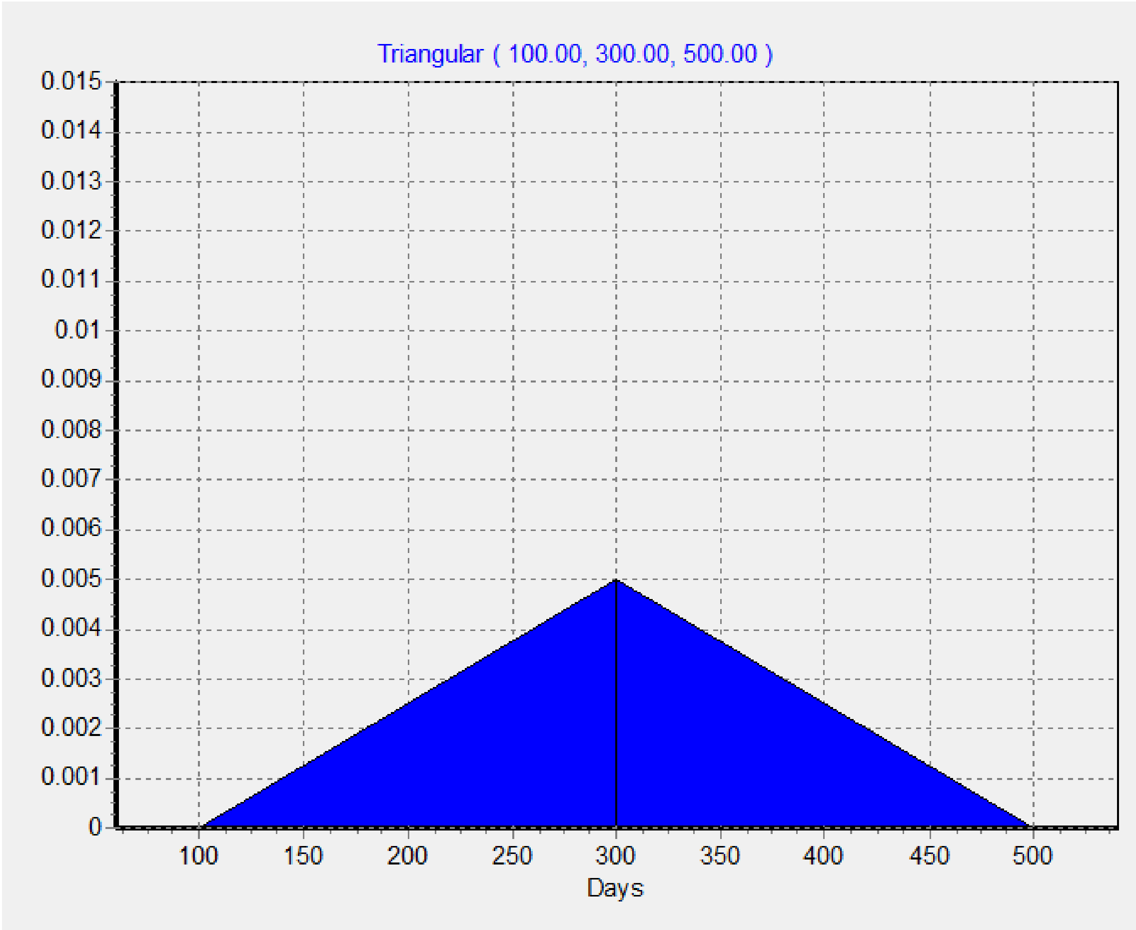

Figure A.11 Defining the Duration of the *Immune* Period for Lamb

Table A.1 Production Type Combinations (i.e., FMD can spread between these production types)

Feedlot to Feedlot
Feedlot to Cow-calf
Feedlot to Swine
Feedlot to Dairy
Feedlot to Sheep
Cow-calf to Feedlot
Cow-calf to Cow-calf
Cow-calf to Swine
Cow-calf to Dairy
Cow-calf to Sheep
Swine to Feedlot
Swine to Cow-calf
Swine to Swine
Swine to Dairy
Swine to Sheep
Dairy to Feedlot
Dairy to Cow-calf
Dairy to Swine
Dairy to Dairy
Dairy to Sheep
Sheep to Feedlot
Sheep to Cow-calf
Sheep to Swine
Sheep to Dairy
Sheep to Sheep

Table A.2. Contact Disease Spread (Direct Contact)

Production Types	Latent units can spread disease	Subclinical units can spread disease	Use fix contact rate	Mean contact rate (recipient units/unit/day)
Feedlot to Feedlot	Yes	Yes	No	0.1
Feedlot to Cow-calf	Yes	Yes	No	0.0003
Feedlot to Swine	Yes	Yes	No	0
Feedlot to Dairy	Yes	Yes	No	0.0003
Feedlot to Sheep	Yes	Yes	No	0.0003
Cow-calf to Feedlot	Yes	Yes	No	0.00005
Cow-calf to Cow-calf	Yes	Yes	No	0.0008
Cow-calf to Swine	Yes	Yes	No	0
Cow-calf to Dairy	Yes	Yes	No	0
Cow-calf to Sheep	Yes	Yes	No	0.0008
Swine to Feedlot	Yes	Yes	No	0
Swine to Cow-calf	Yes	Yes	No	0
Swine to Swine	Yes	Yes	No	0.33
Swine to Dairy	Yes	Yes	No	0
Swine to Sheep	Yes	Yes	No	0
Dairy to Feedlot	Yes	Yes	No	0.28
Dairy to Cow-calf	Yes	Yes	No	0
Dairy to Swine	Yes	Yes	No	0
Dairy to Dairy	Yes	Yes	No	0.57
Dairy to Sheep	Yes	Yes	No	0
Sheep to Feedlot	Yes	Yes	No	0.00005
Sheep to Cow-calf	Yes	Yes	No	0.0008
Sheep to Swine	Yes	Yes	No	0
Sheep to Dairy	Yes	Yes	No	0
Sheep to Sheep	Yes	Yes	No	0.0008

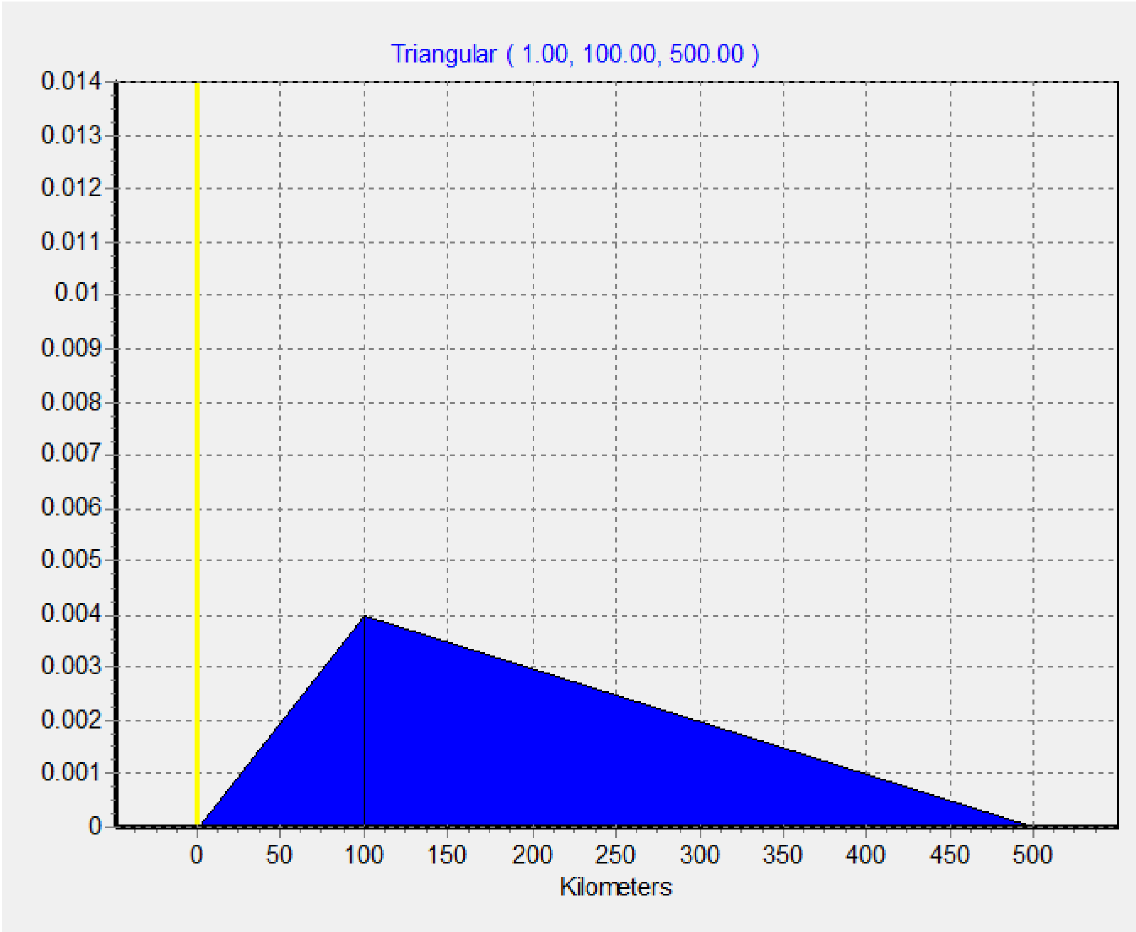

Figure A.12 Distance Distribution of Recipient Units (Feedlot to Feedlot)

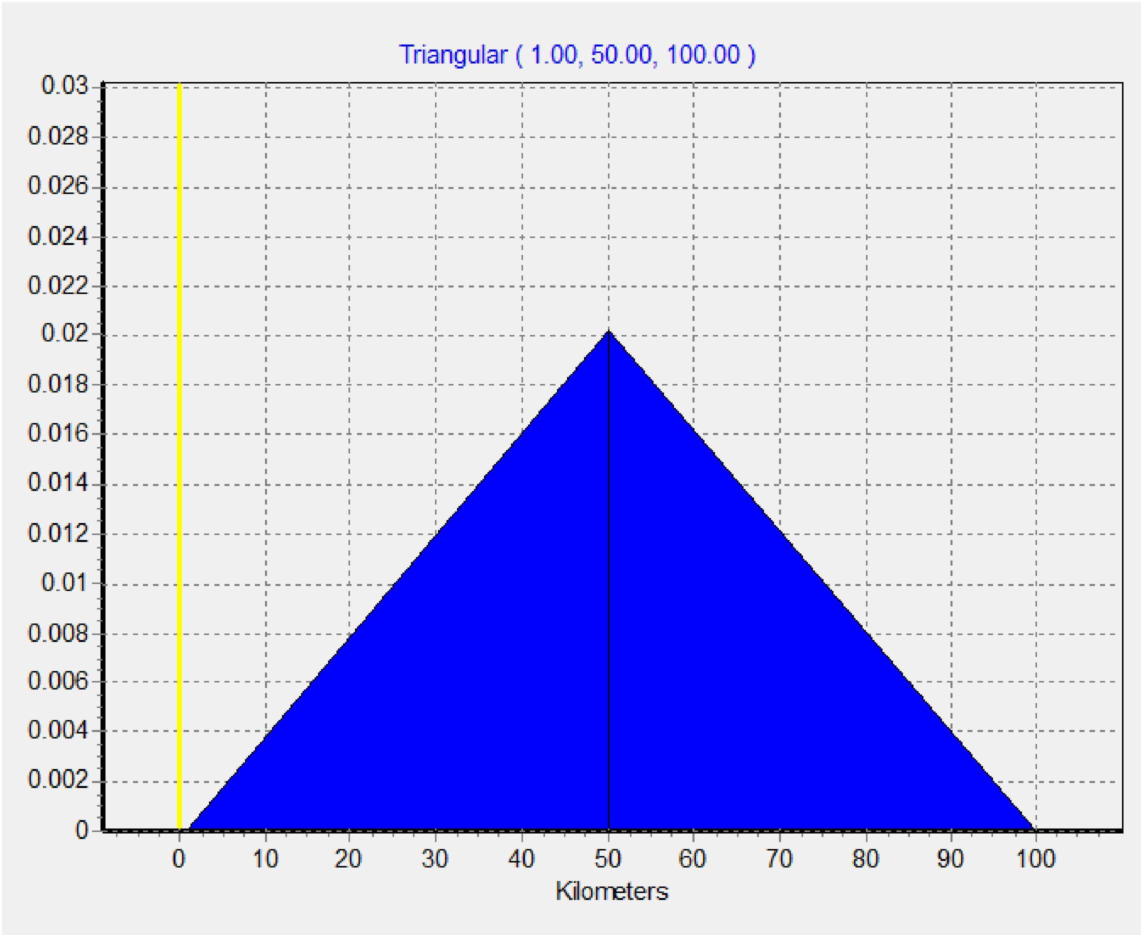

Figure A.13 Distance Distribution of Recipient Units (Feedlot to: Cow-calf, Dairy, and Sheep)

Distance distribution of recipient units (Feedlot to Swine) - Direct Contact

Distribution is a Fixed Value and is zero

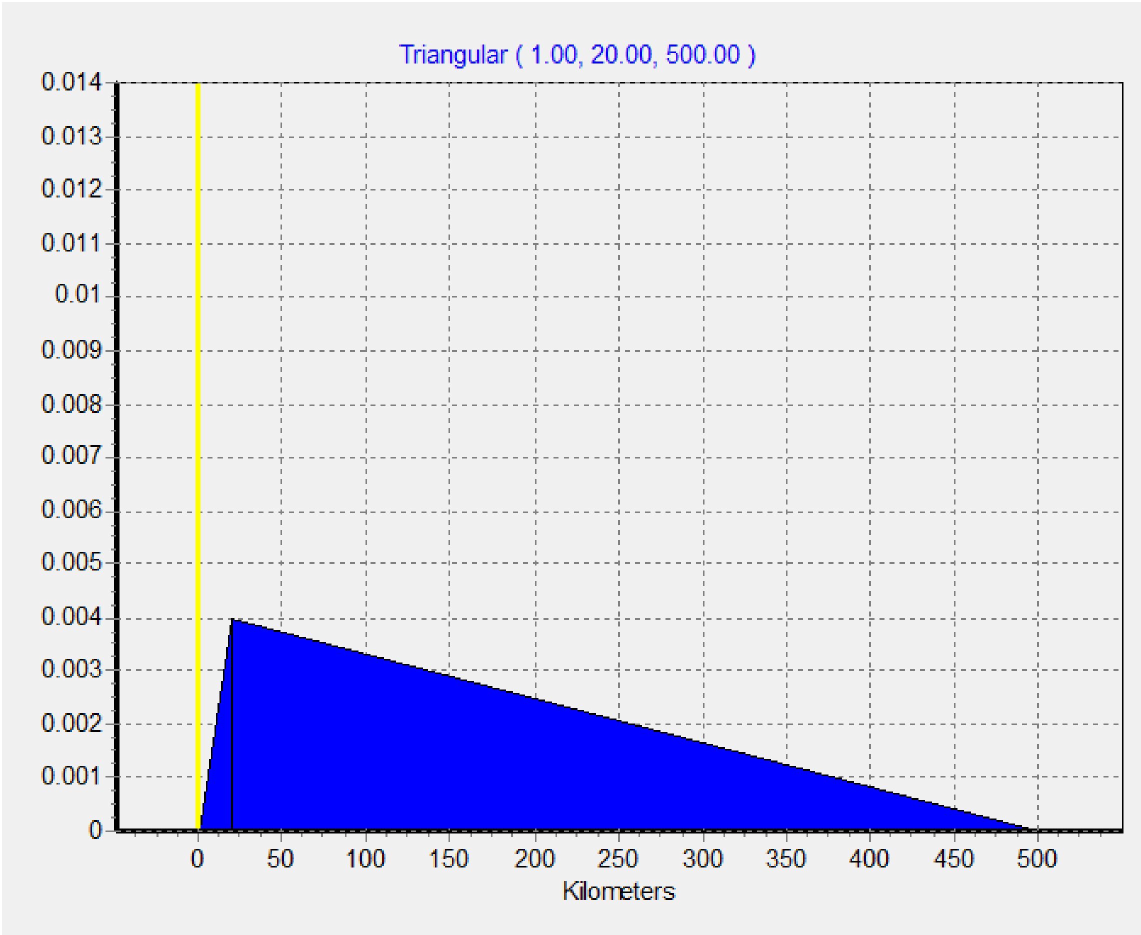

Figure A.14 Distance Distribution of Recipient Units (Cow-calf to Cow-calf)

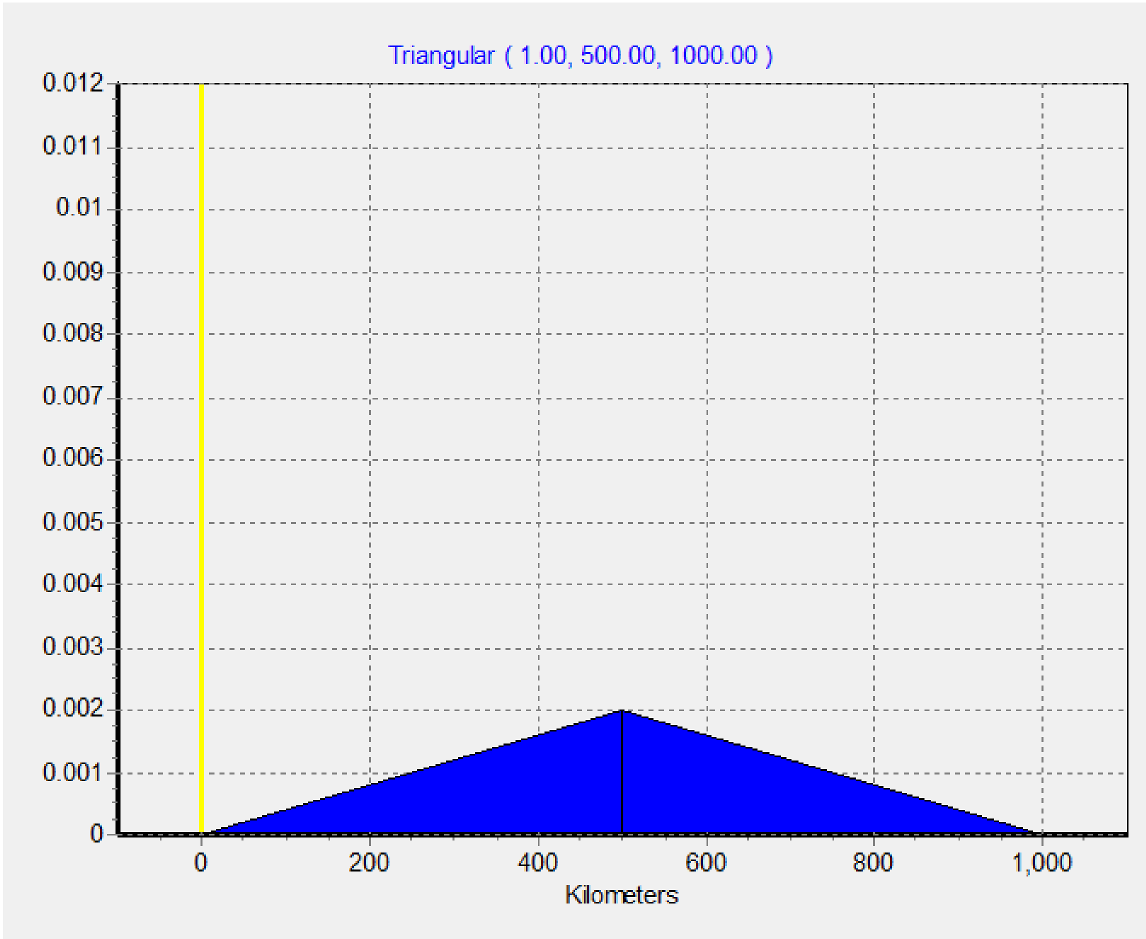

Figure A.15 Distance Distribution of Recipient Units (Cow-calf to Feedlot)

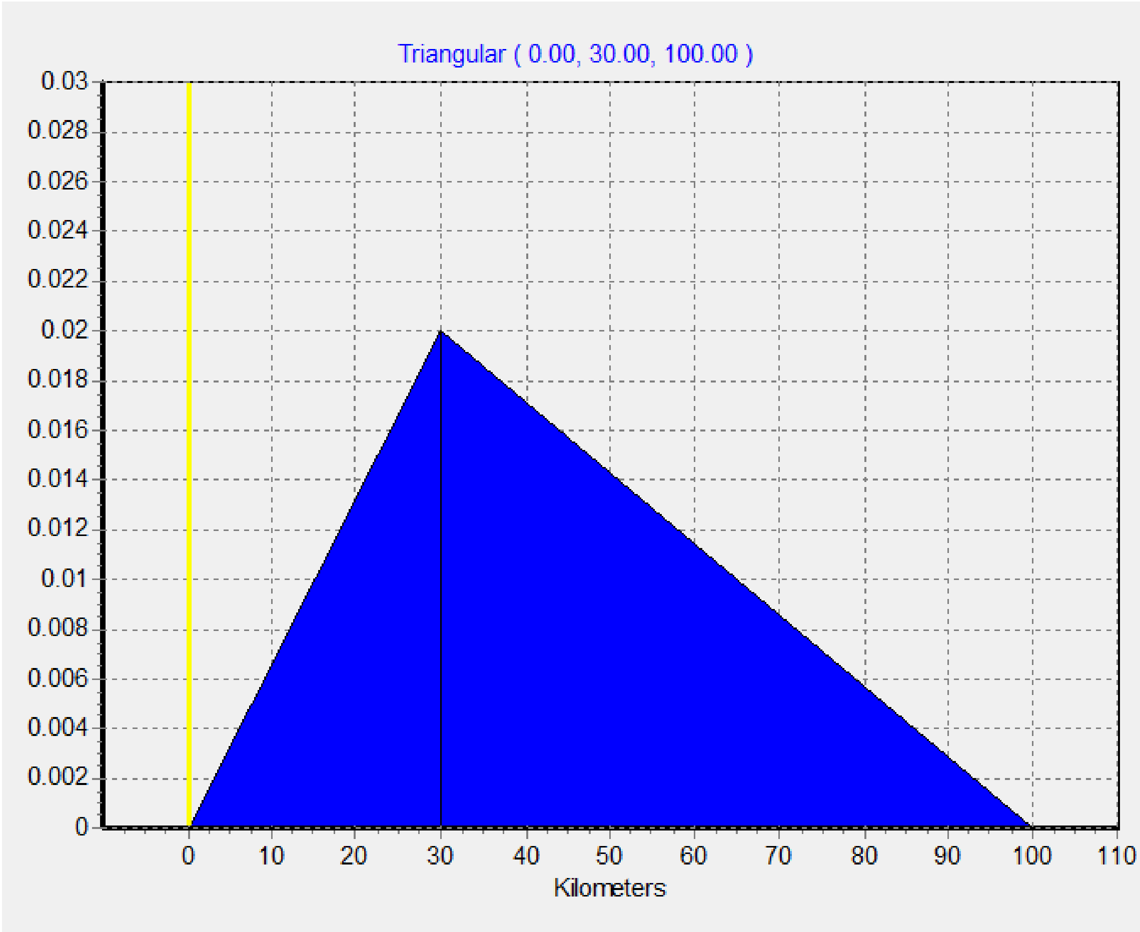

Figure A.16 Distance Distribution of Recipient Units (Cow-calf to Dairy)

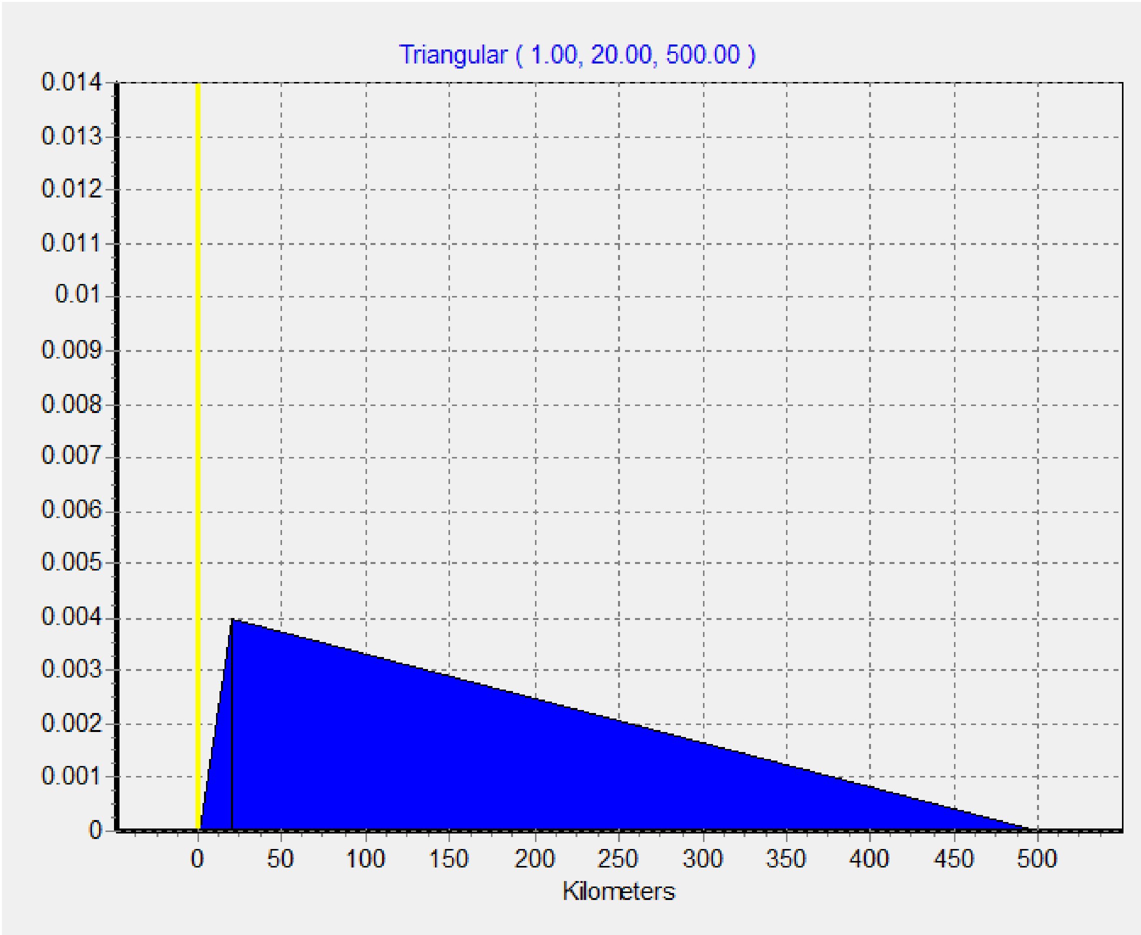

Figure A.17 Distance Distribution of Recipient Units (Cow-calf to Sheep)

Distance distribution of recipient units (Cow-calf to Swine) - Direct Contact

Distribution is a Fixed Value and is zero

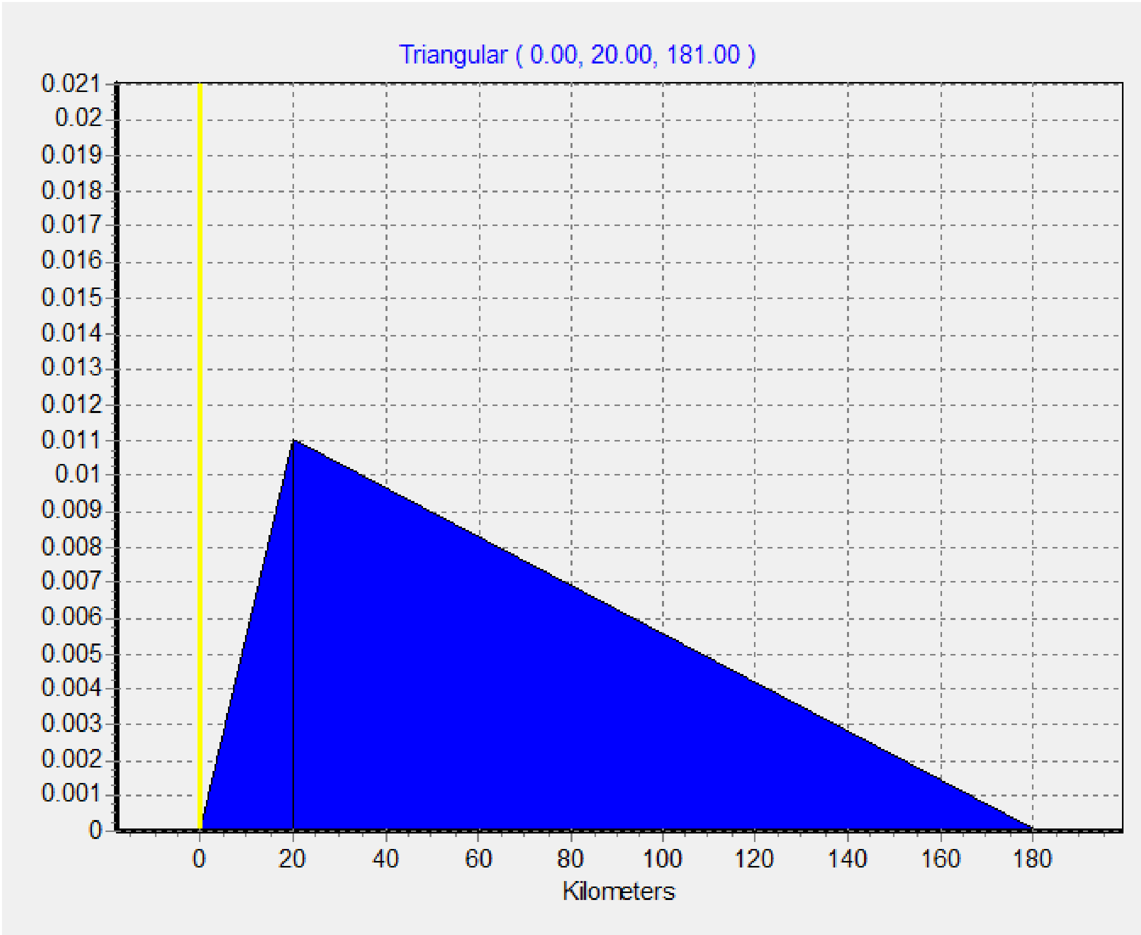

Figure A.18 Distance Distribution of Recipient Units (Swine to Swine)

Distance distribution of recipient units (Swine to: Feedlot, Cow-calf, Dairy, and Sheep) - Direct Contact

Distribution is a Fixed Value and is zero

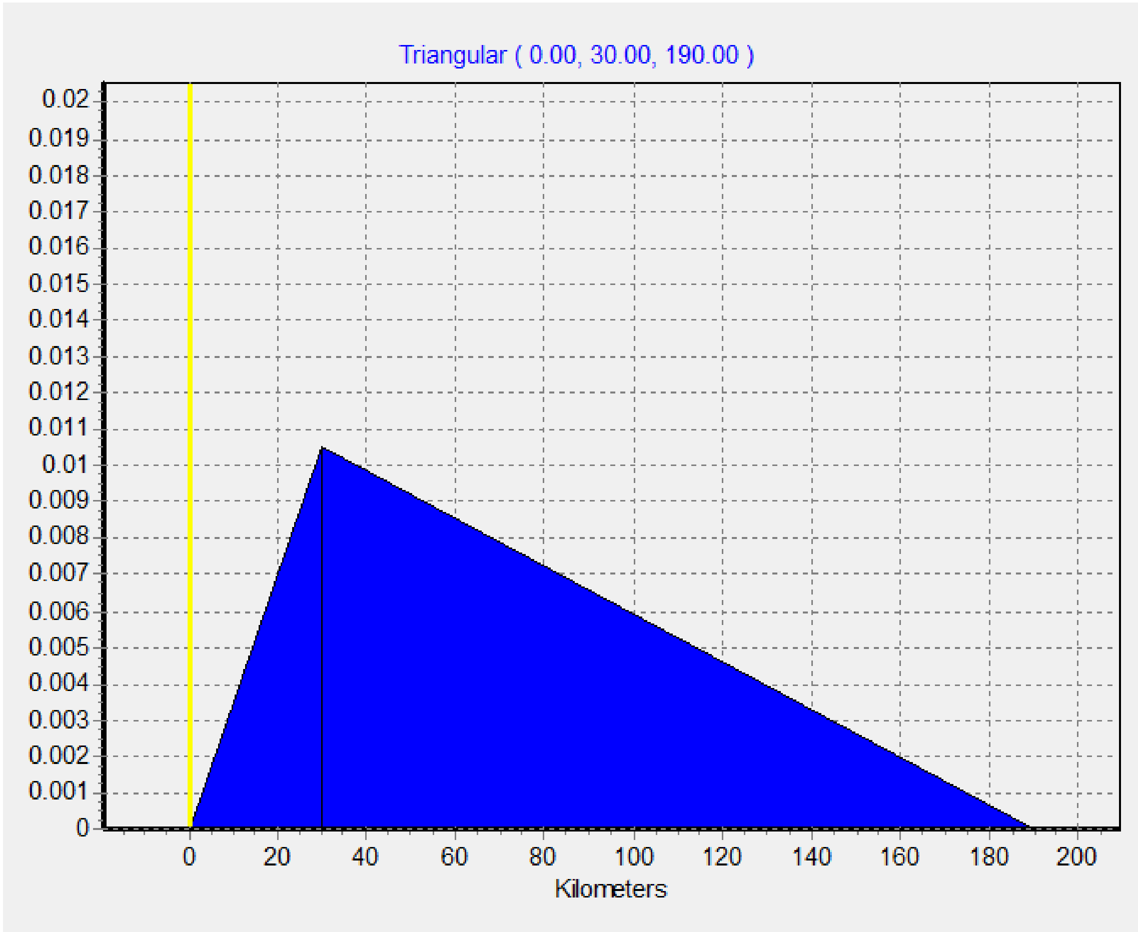

Figure A.19 Distance Distribution of Recipient Units (Dairy to: Dairy, and Feedlots)

Distance distribution of recipient units (Dairy: to Sheep, and Swine) - Direct Contact

Distribution is a Fixed Value and is zero

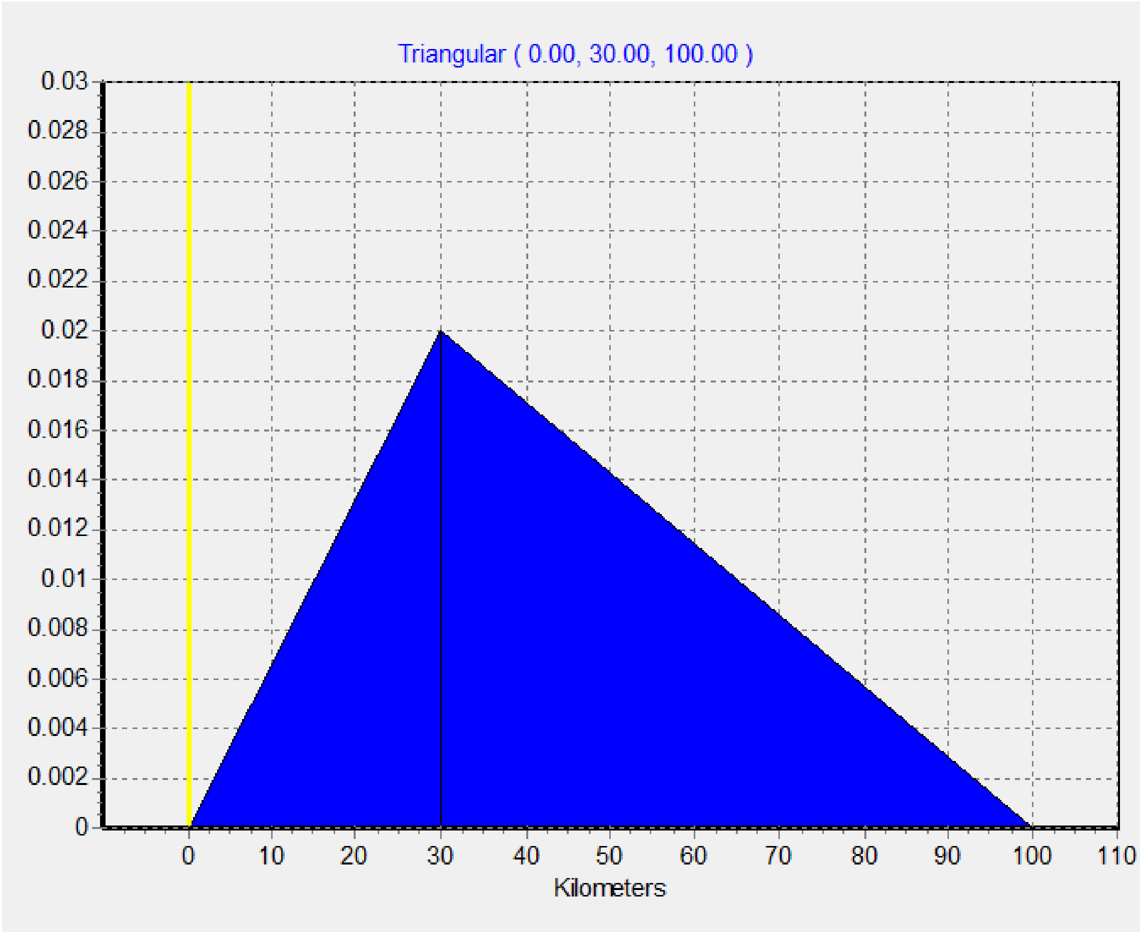

Figure A.20 Distance Distribution of Recipient Units (Dairy to Cow-calf)

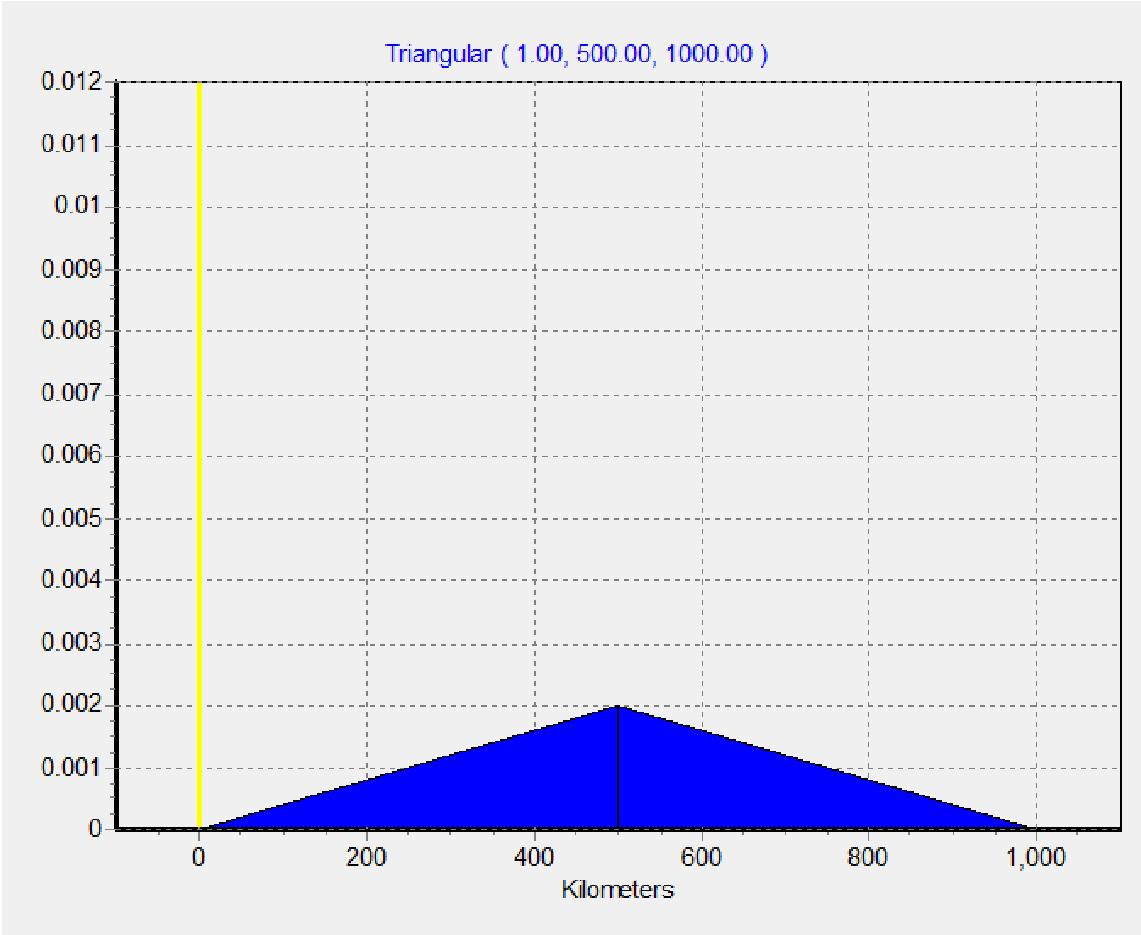

Figure A.21 Distance Distribution of Recipient Units (Sheep to Feedlots)

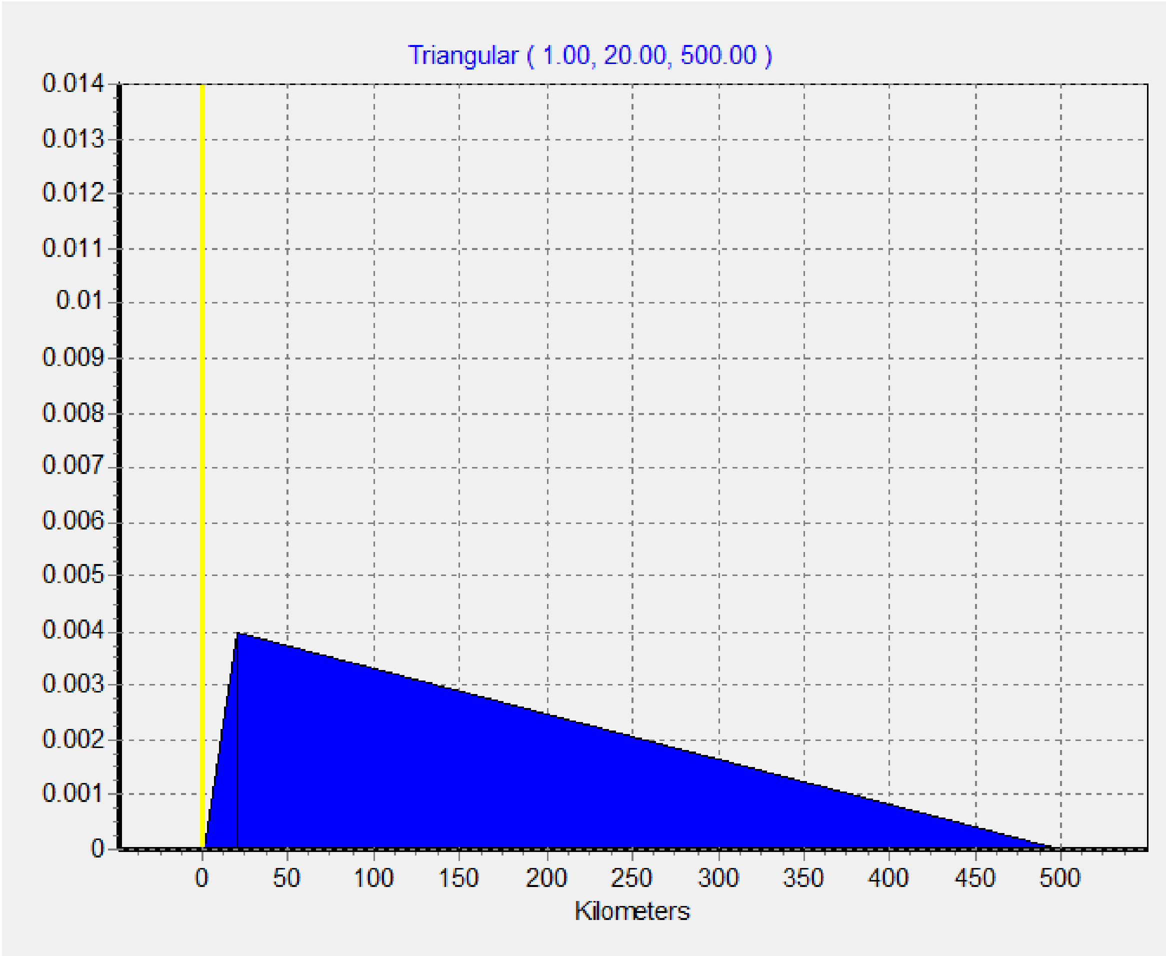

Figure A.22 Distance Distribution of Recipient Units (Sheep to: Cow-calf, and Sheep)

Distance distribution of recipient units (Sheep to: Swine, and Dairy) - Direct Contact

Distribution is a Fixed Value and is zero

Table A.3 Contact Disease Spread (Indirect Contact)

Production Types	Latent units can spread disease	Subclinical units can spread disease	Use fix contact rate	Mean contact rate (recipient units/unit/day)	Probability of infection transfer
Feedlot to Feedlot	Yes	Yes	No	12.8	0.1
Feedlot to Cow-calf	Yes	Yes	No	0.026	0.1
Feedlot to Swine	Yes	Yes	No	0	0.15
Feedlot to Dairy	Yes	Yes	No	0.75	0.1
Feedlot to Sheep	Yes	Yes	No	0.026	0.1
Cow-calf to Feedlot	Yes	Yes	No	0.8	0.1
Cow-calf to Cow-calf	Yes	Yes	No	0.078	0.1
Cow-calf to Swine	Yes	Yes	No	0	0.15
Cow-calf to Dairy	Yes	Yes	No	0.1	0.1
Cow-calf to Sheep	Yes	Yes	No	0.078	0.1
Swine to Feedlot	Yes	Yes	No	0	0.15
Swine to Cow-calf	Yes	Yes	No	0	0.15
Swine to Swine	Yes	Yes	No	5.3	0.2
Swine to Dairy	Yes	Yes	No	0	0.15
Swine to Sheep	Yes	Yes	No	0	0.15
Dairy to Feedlot	Yes	Yes	No	2.4	0.1
Dairy to Cow-calf	Yes	Yes	No	0.026	0.1
Dairy to Swine	Yes	Yes	No	0	0.15
Dairy to Dairy	Yes	Yes	No	24.76	0.1
Dairy to Sheep	Yes	Yes	No	0.026	0.1
Sheep to Feedlot	Yes	Yes	No	0.8	0.1
Sheep to Cow-calf	Yes	Yes	No	0.078	0.1
Sheep to Swine	Yes	Yes	No	0	0.15
Sheep to Dairy	Yes	Yes	No	0.1	0.1
Sheep to Sheep	Yes	Yes	No	0.078	0.1

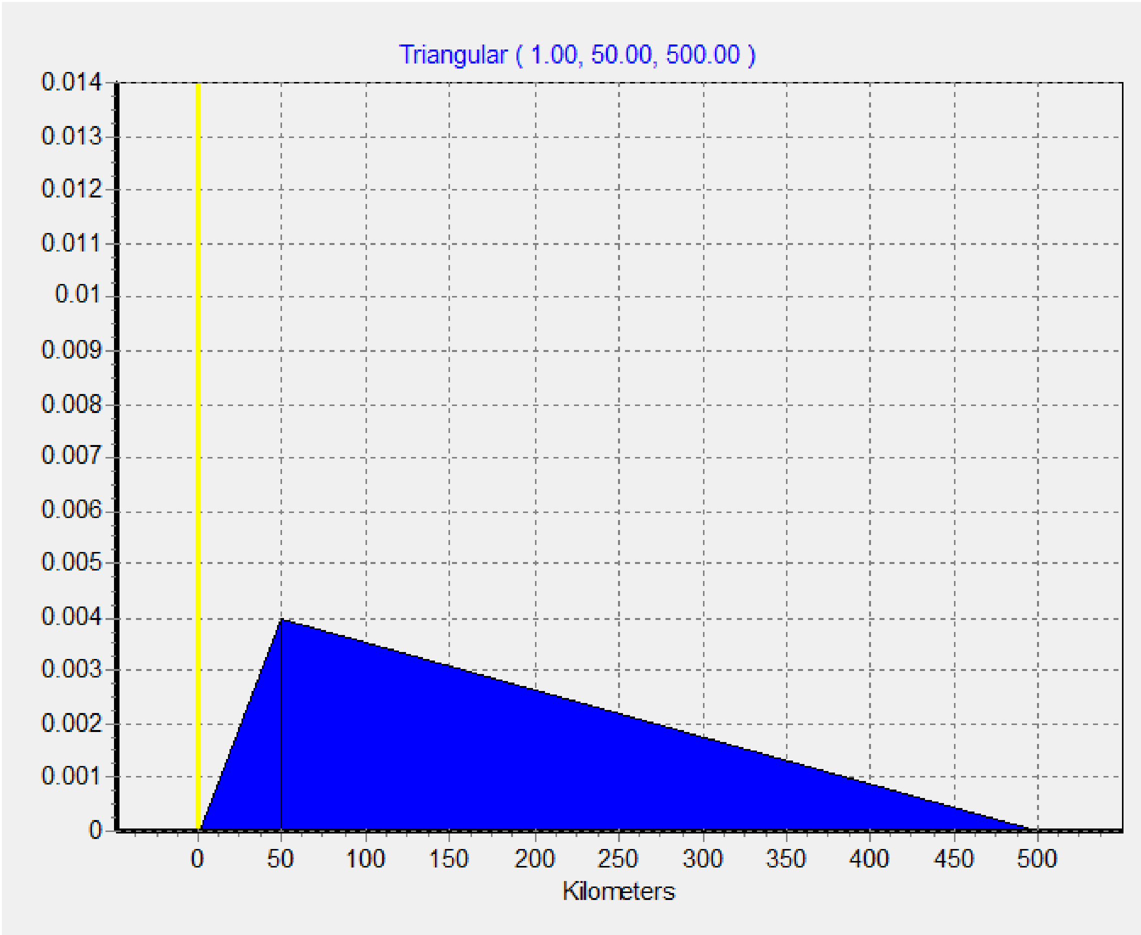

Figure A.23 Distance Distribution of Recipient Units (Feedlot to Feedlot)

Distance distribution of recipient units (Feedlot to Swine) - Indirect Contact

Distribution is a Fixed Value and is zero

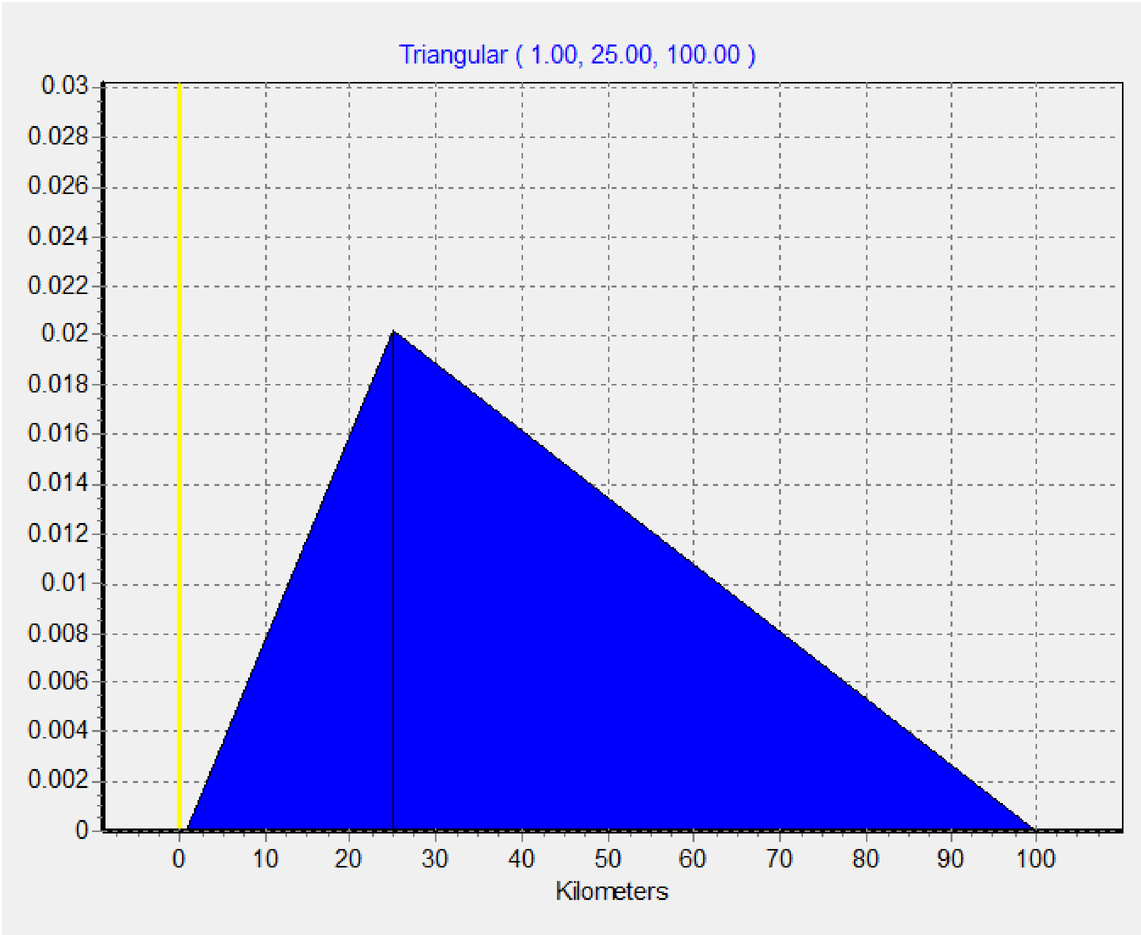

Figure A.24 Distance Distribution of Recipient Units (Cow-calf to: Feedlot, Cow-calf, and Sheep)

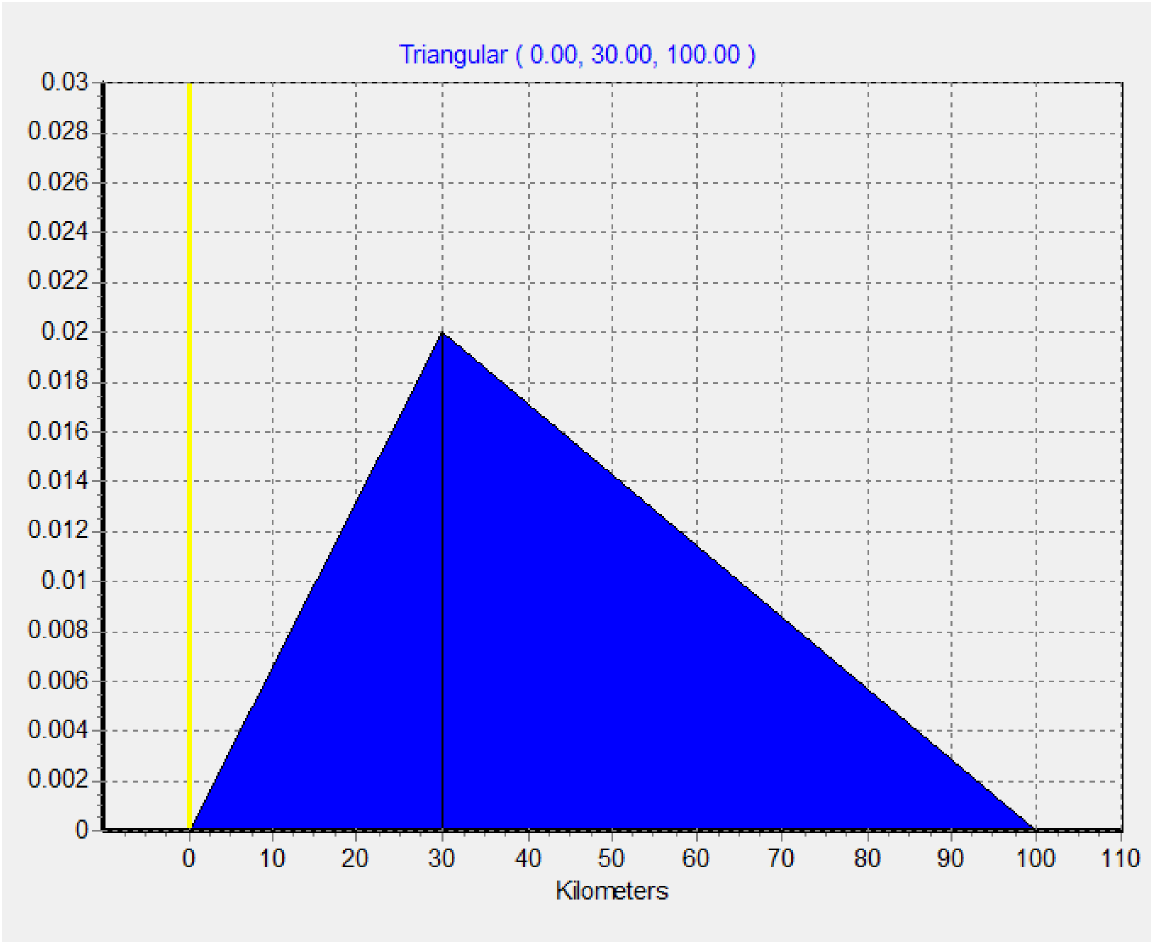

Figure A.25 Distance Distribution of Recipient Units (Cow-calf to Dairy)

Distance distribution of recipient units (Cow-calf to Swine) - Indirect Contact

Distribution is a Fixed Value and is zero

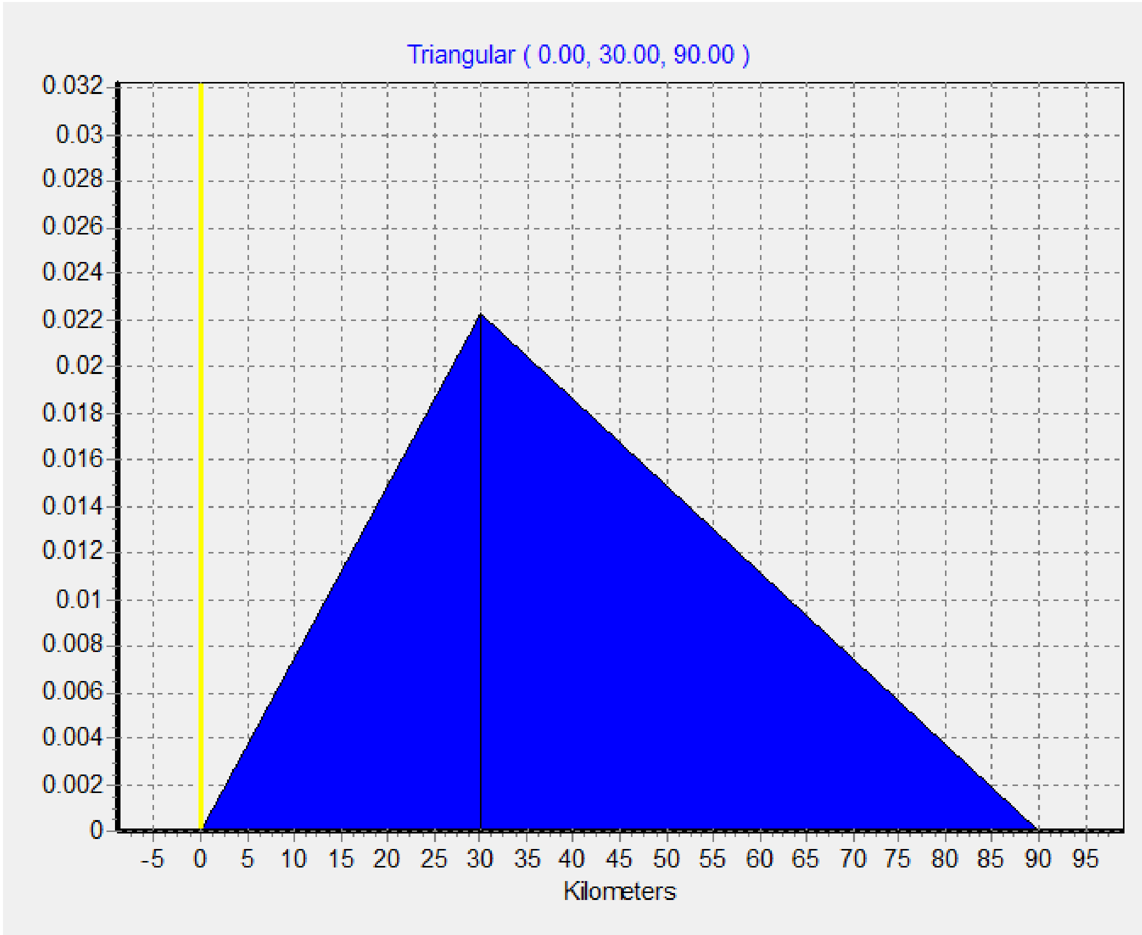

Figure A.26 Distance Distribution of Recipient Units (Swine to Swine)

Distance distribution of recipient units (Swine to: Feedlots, Cow-calf, Dairy, and Sheep) - Indirect Contact

Distribution is a Fixed Value and is zero

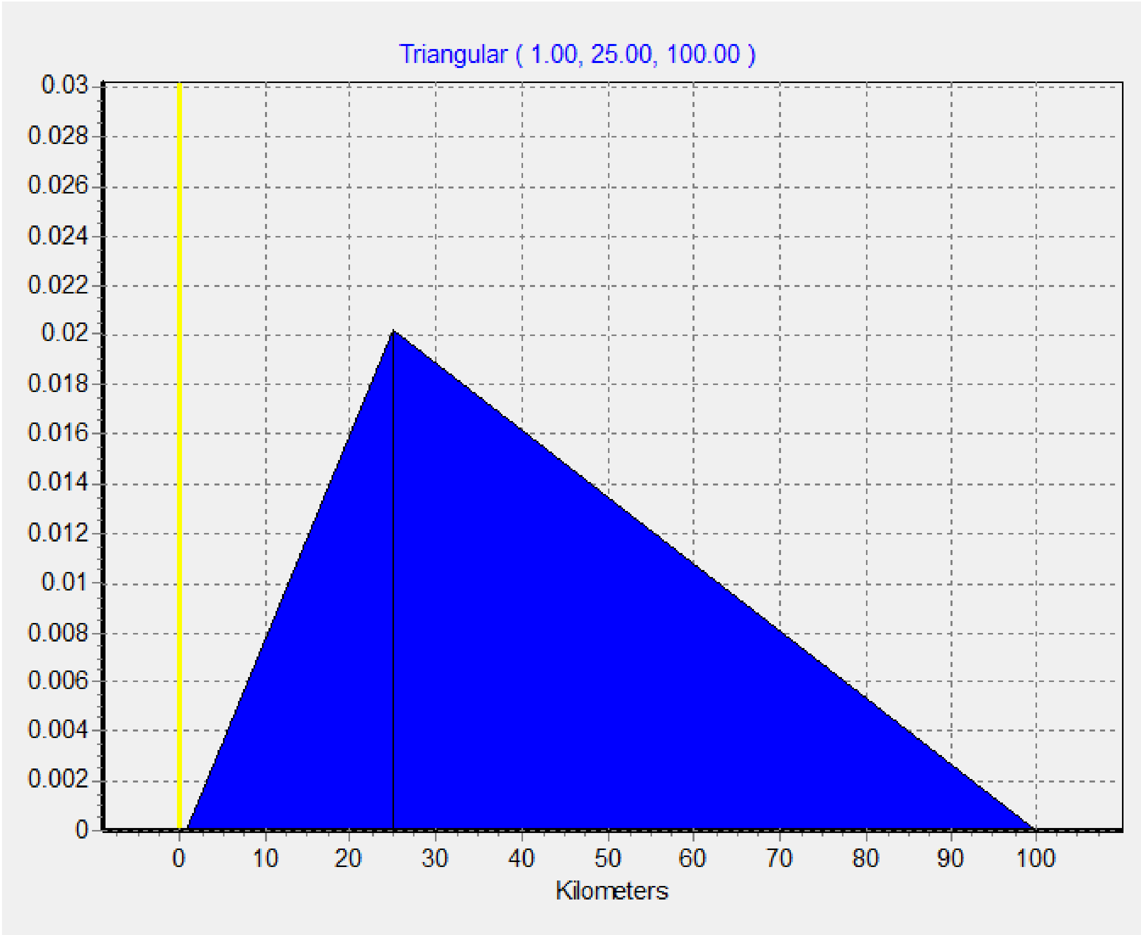

Figure A.27 Distance Distribution of Recipient Units (Dairy to: Feedlot, Cow-calf, and Sheep)

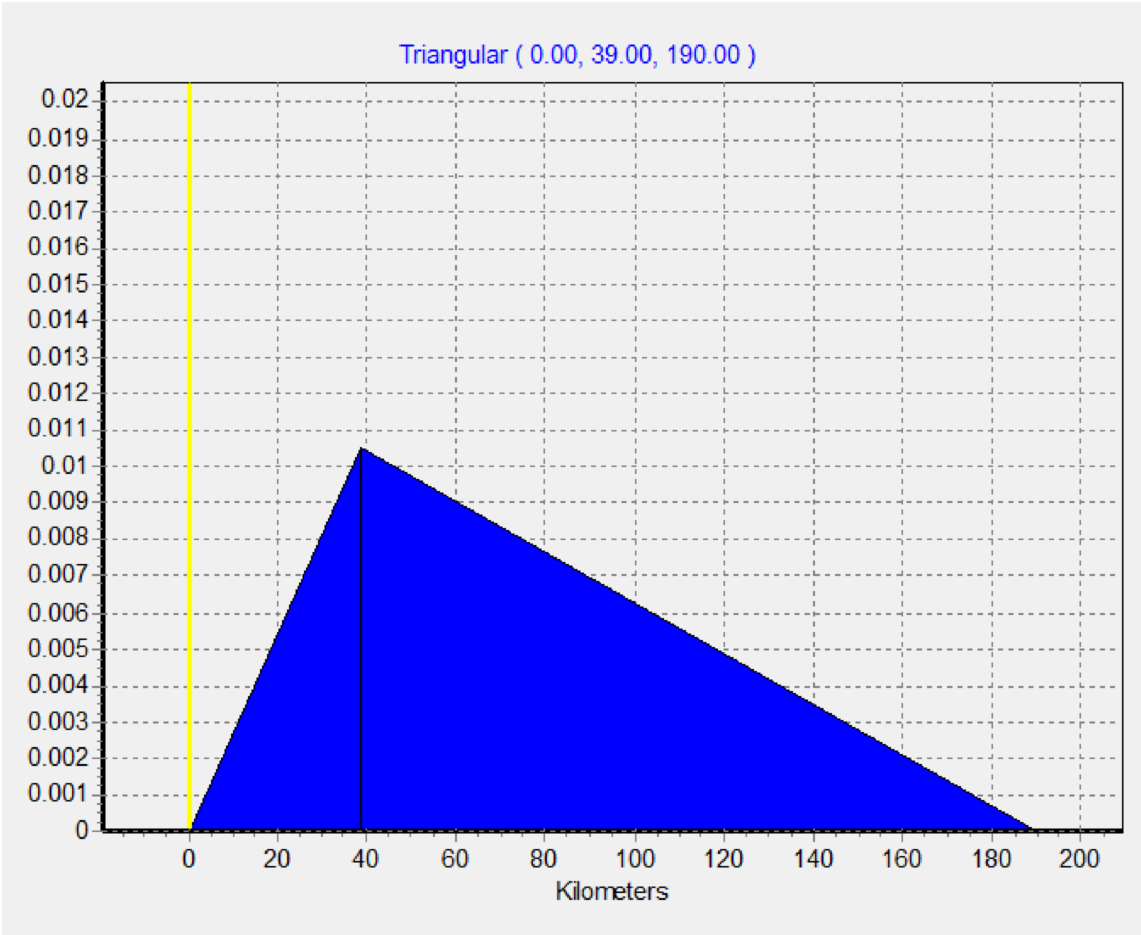

Figure A.28 Distance Distribution of Recipient Units (Dairy to Dairy)

Distance distribution of recipient units (Dairy to Swine) - Indirect Contact

Distribution is a Fixed Value and is zero

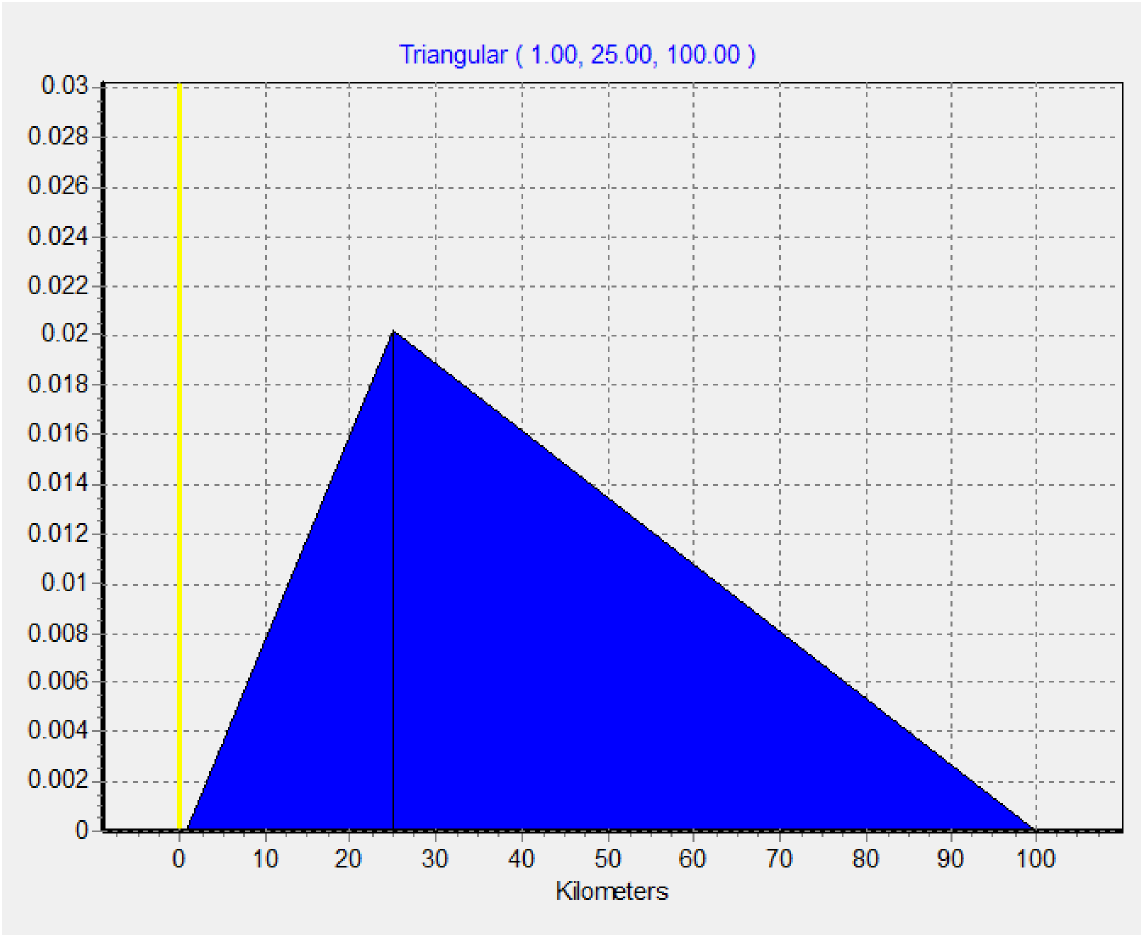

Figure A.29 Distance Distribution of Recipient Units (Sheep to: Feedlot, Cow-calf, and Sheep)

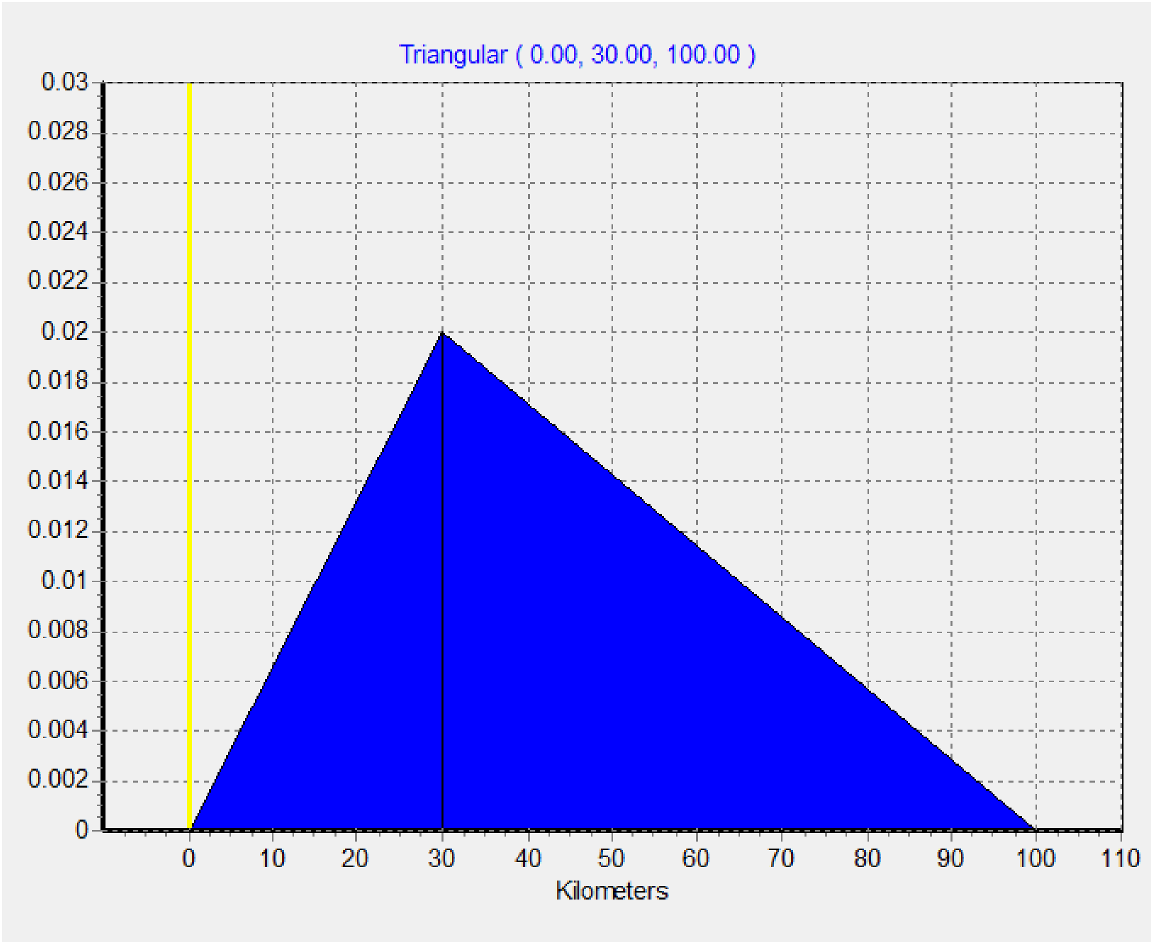

Figure A.30 Distance Distribution of Recipient Units (Sheep to Dairy)

Distance distribution of recipient units (Sheep to Swine) - Indirect Contact

Distribution is a Fixed Value and is zero

Table A.4 Airborne Disease Spread

Production Types	Probability spread/contagious days, at 1km average unit size
Feedlot to Feedlot	0.02
Feedlot to Cow-calf	0.02
Feedlot to Swine	0.02
Feedlot to Dairy	0.02
Feedlot to Sheep	0.02
Cow-calf to Feedlot	0.02
Cow-calf to Cow-calf	0.02
Cow-calf to Swine	0.02
Cow-calf to Dairy	0.02
Cow-calf to Sheep	0.02
Swine to Feedlot	0.02
Swine to Cow-calf	0.02
Swine to Swine	0.02
Swine to Dairy	0.02
Swine to Sheep	0.02
Dairy to Feedlot	0.02
Dairy to Cow-calf	0.02
Dairy to Swine	0.02
Dairy to Dairy	0.02
Dairy to Sheep	0.02
Sheep to Feedlot	0.02
Sheep to Cow-calf	0.02
Sheep to Swine	0.02
Sheep to Dairy	0.02
Sheep to Sheep	0.02

Disease Detection

Disease detection was included in this simulation.

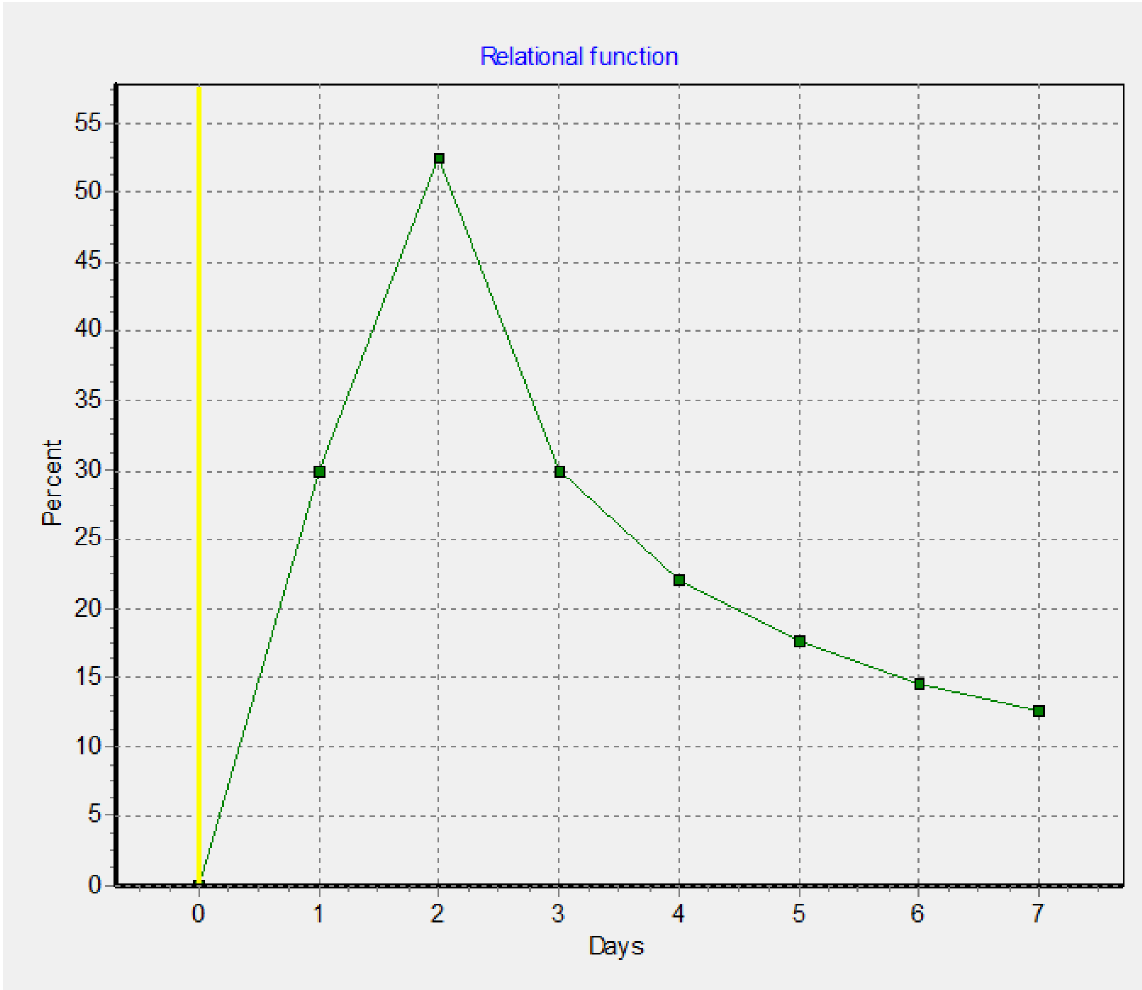

Figure A.31 Probability of observing clinical signs, Given the Number Days the Unit was Infectious (Feedlot)

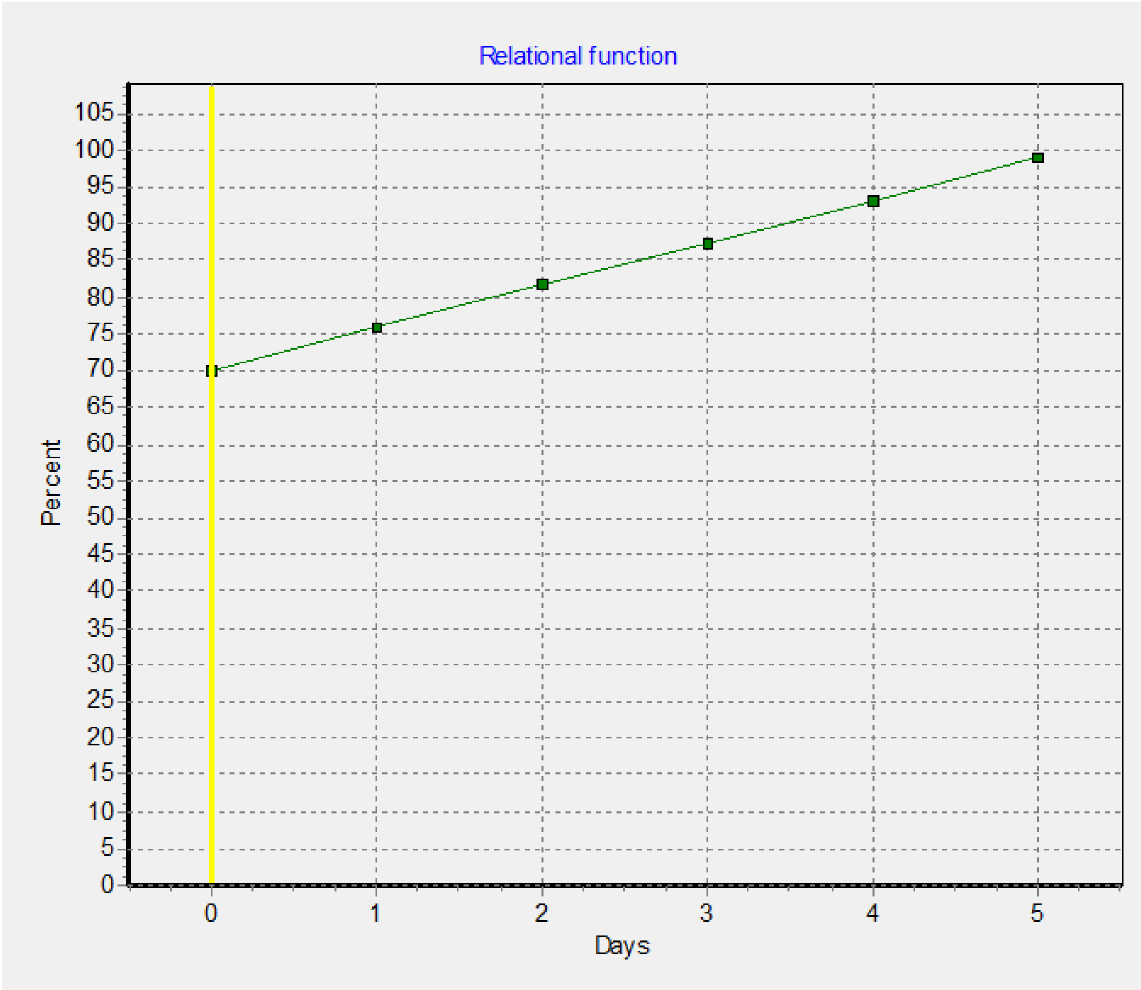

Figure A.32 Probability of Reporting, Given the Number Days the Unit was Detected (Feedlot)

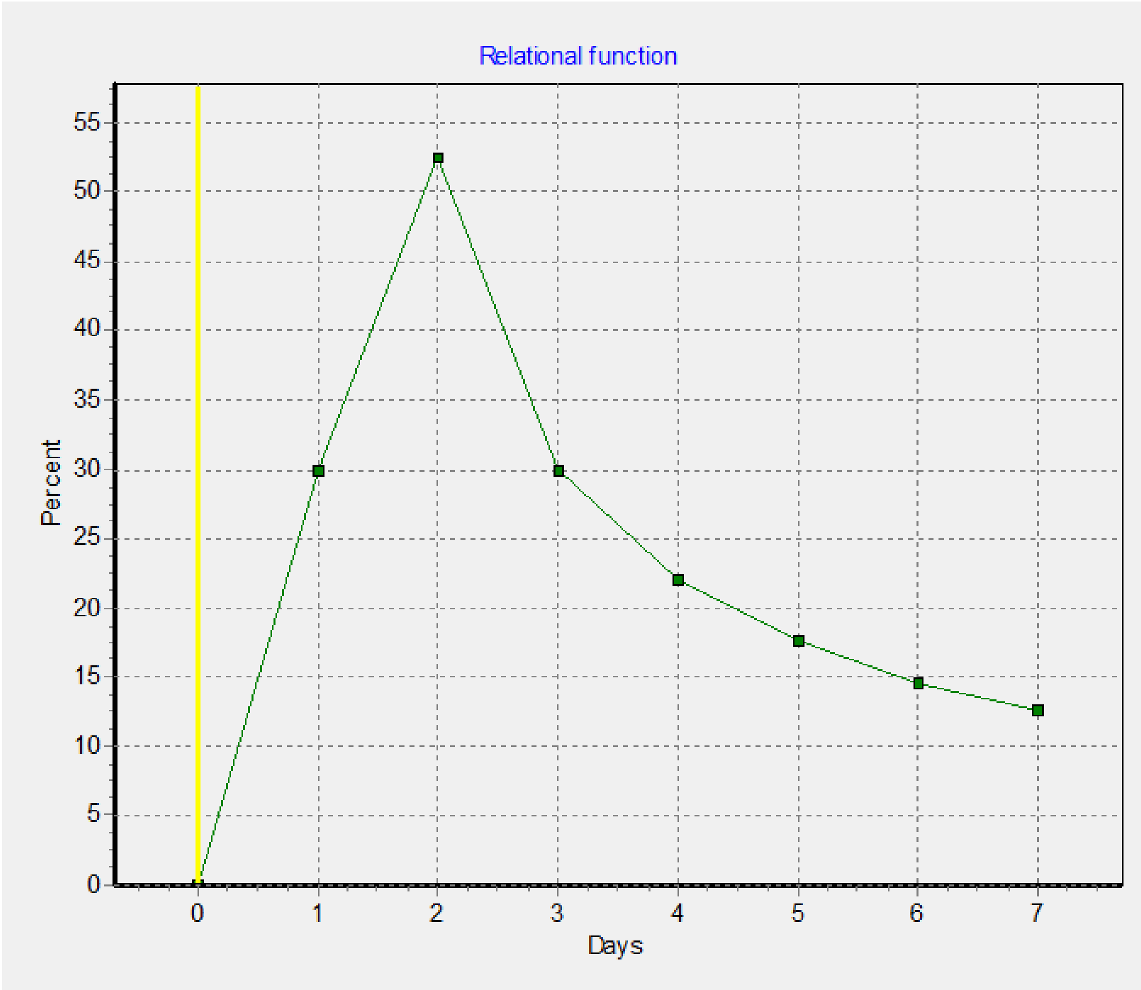

Figure A.33 Probability of observing clinical signs, Given the Number Days the Unit was Infectious (Cow-calf)

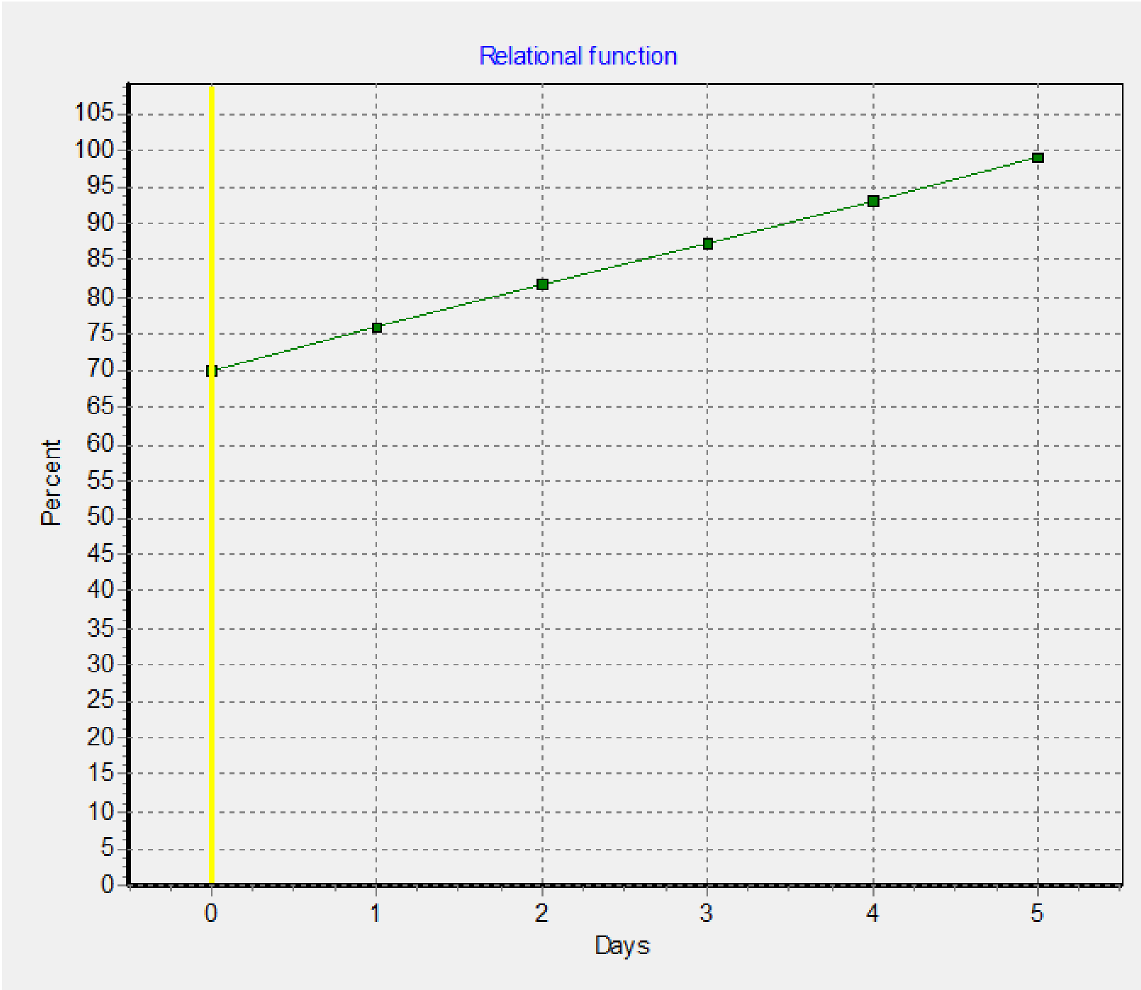

Figure A.34 Probability of Reporting, Given the Number Days the Unit was Detected (Cow-calf)

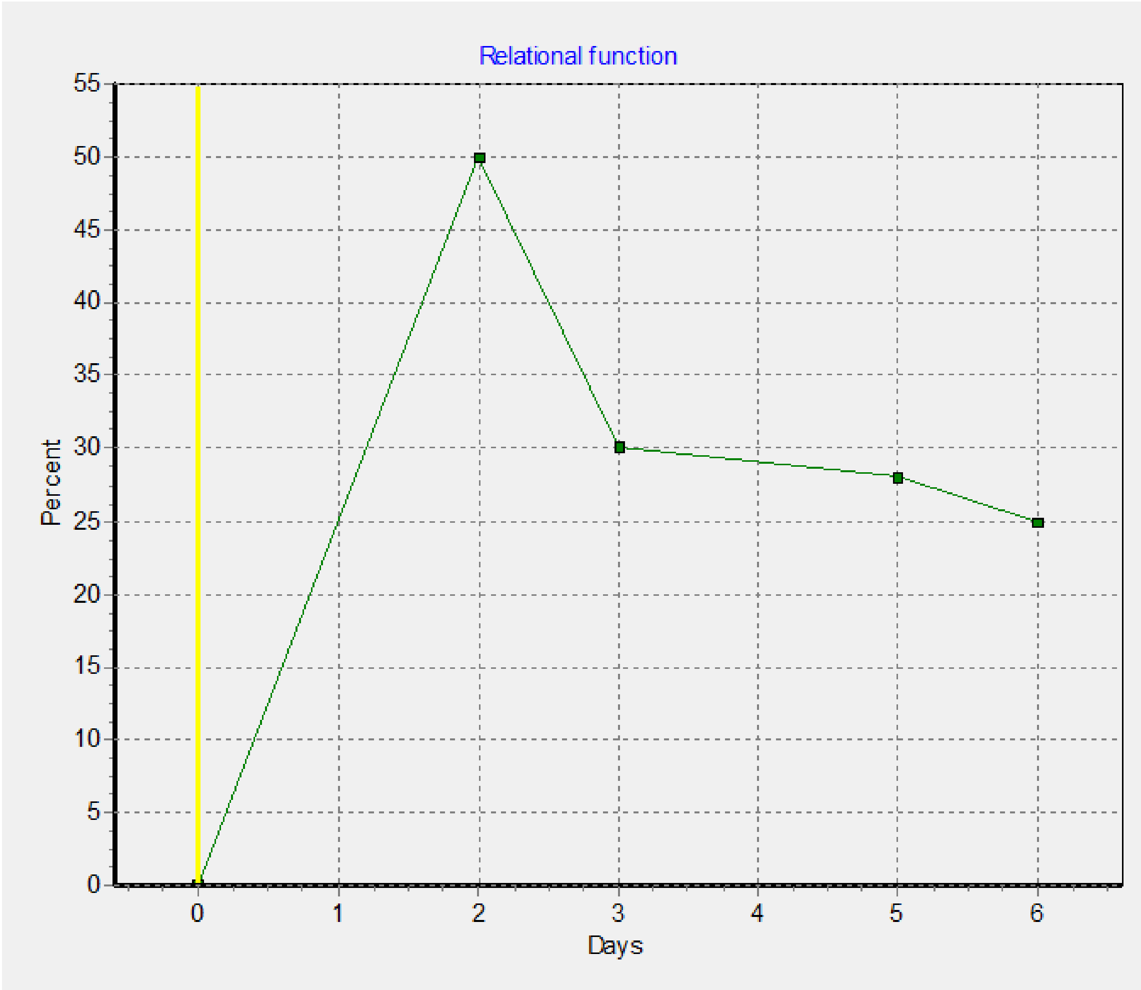

Figure A.35 Probability of observing clinical signs, Given the Number Days the Unit was Infectious (Swine)

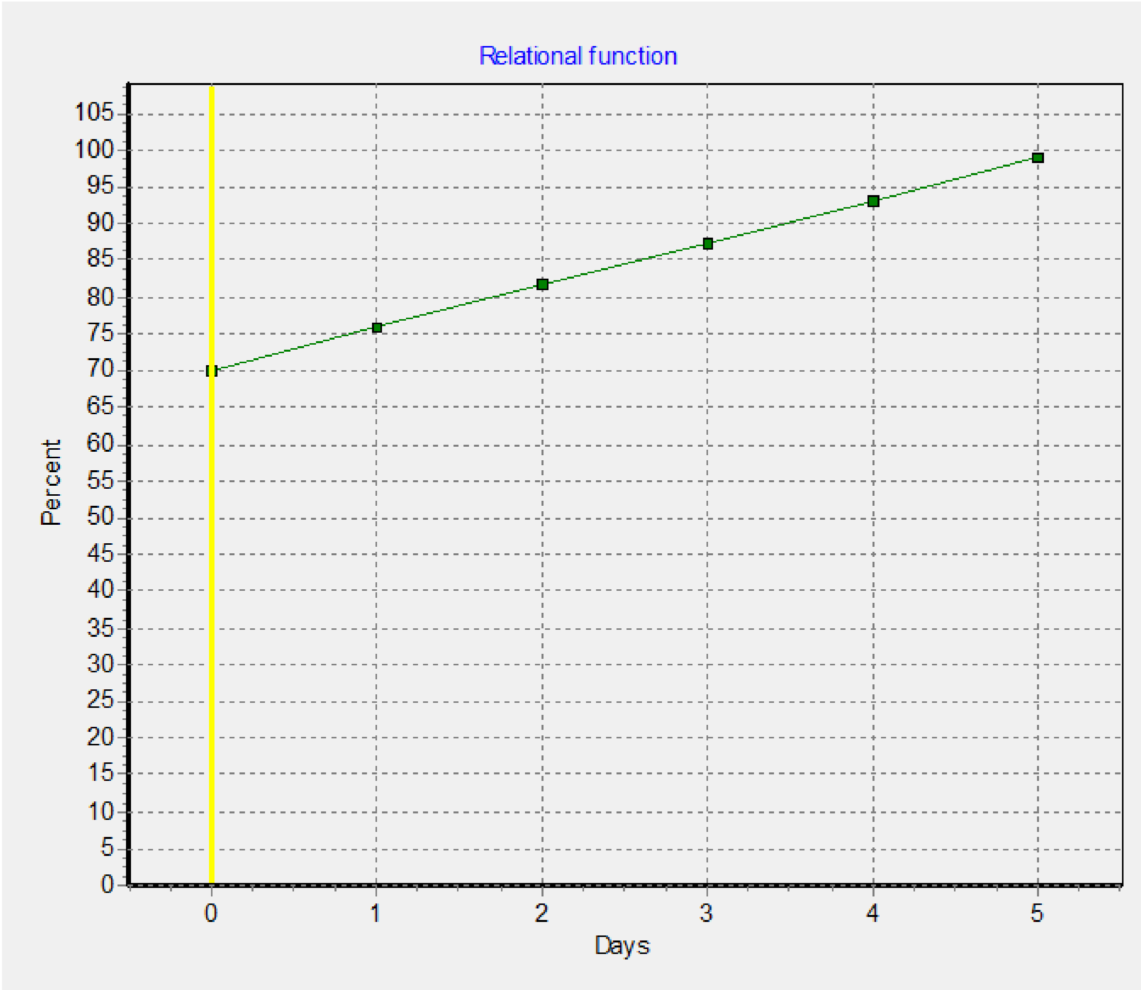

Figure A.36 Probability of Reporting, Given the Number Days the Unit was Detected (Swine)

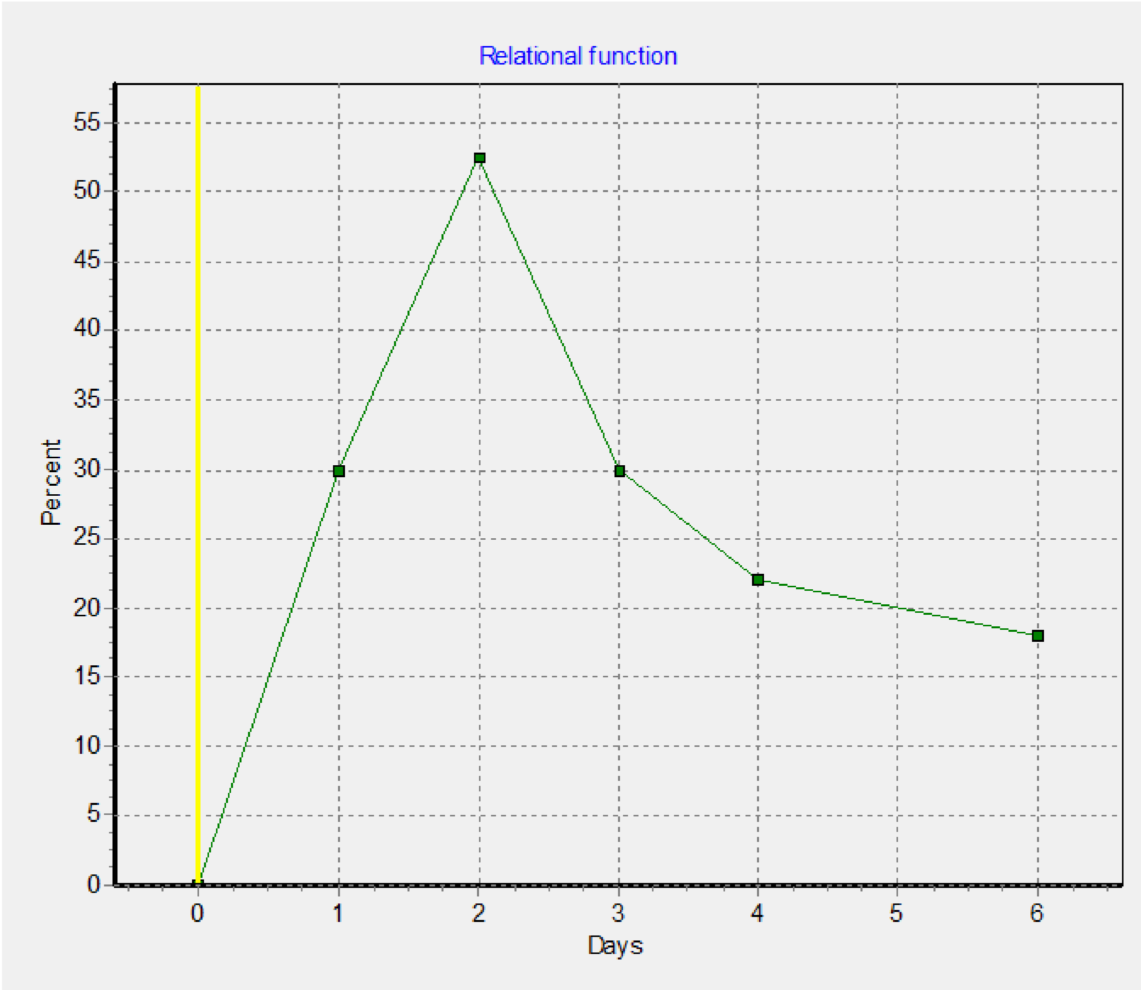

Figure A.37 Probability of observing clinical signs, Given the Number Days the Unit was Infectious (Dairy)

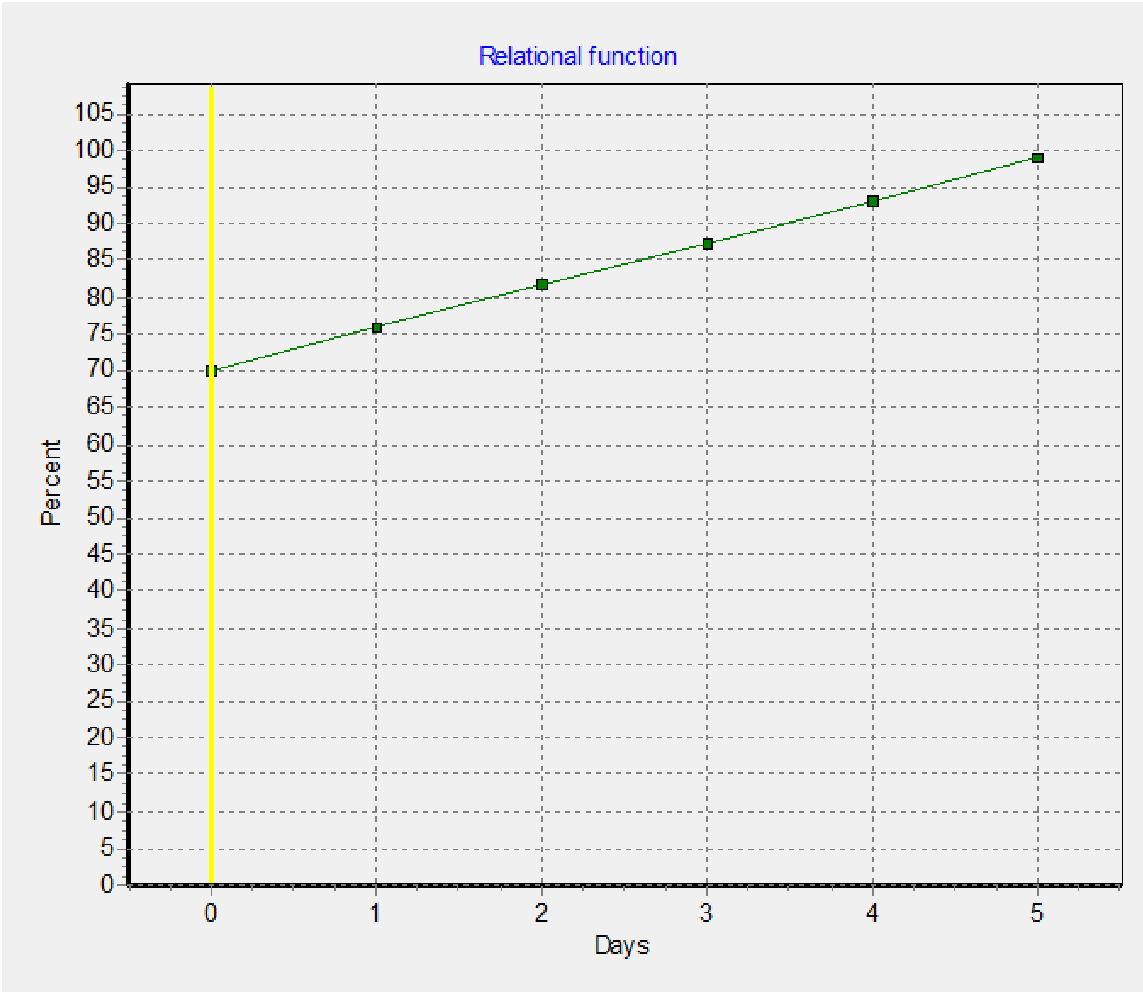

Figure A.38 Probability of Reporting, Given the Number Days the Unit was Detected (Dairy)

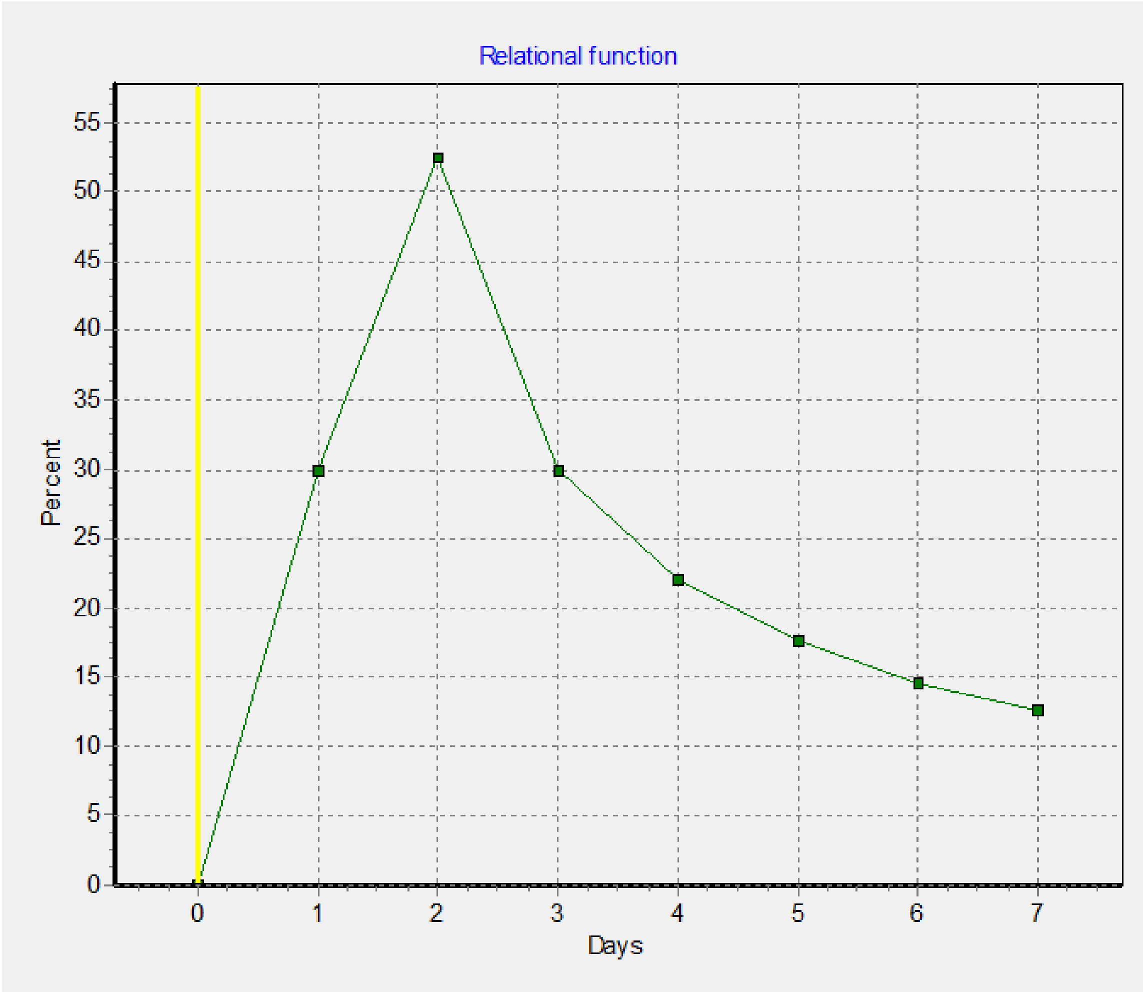

Figure A.39 Probability of observing clinical signs, Given the Number Days the Unit was Infectious (Sheep)

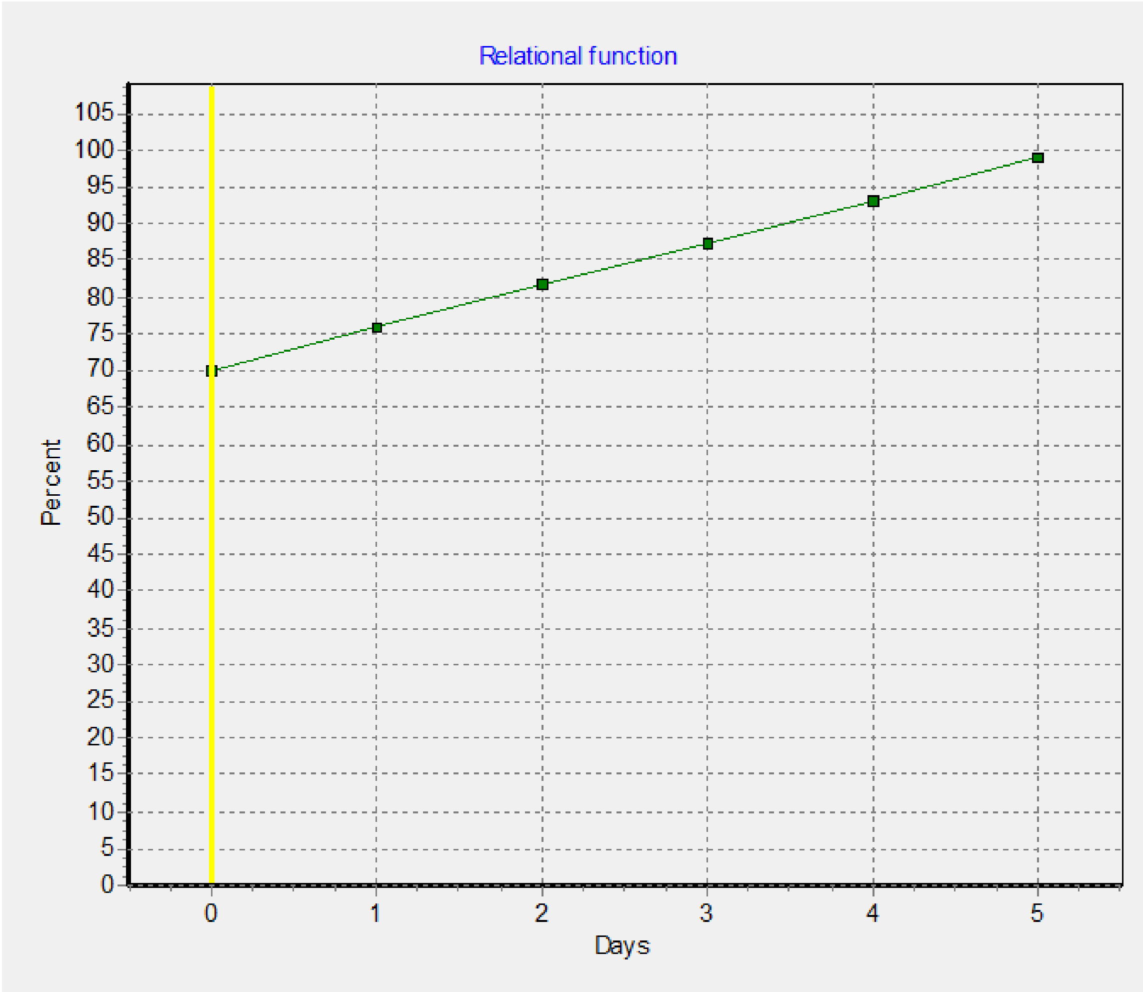

Figure A.40 Probability of Reporting, Given the Number Days the Unit was Detected (Sheep)

Surveillance

Surveillance was included in this simulation.

Table A.5 Surveillance Parameters and Values Used

	Trace Direct Contacts		Trace Indirect Contacts	
Production Type	Contact days before detection	Probability of trace success	Contact days before detection	Probability of trace success
Feedlot	28	0.5	28	0.3
Cow-calf	28	0.5	28	0.3
Swine	28	0.5	28	0.3
Dairy	28	0.5	28	0.3
Sheep	28	0.5	28	0.3

Destruction

Delay before implementing destruction program (days): 3 days

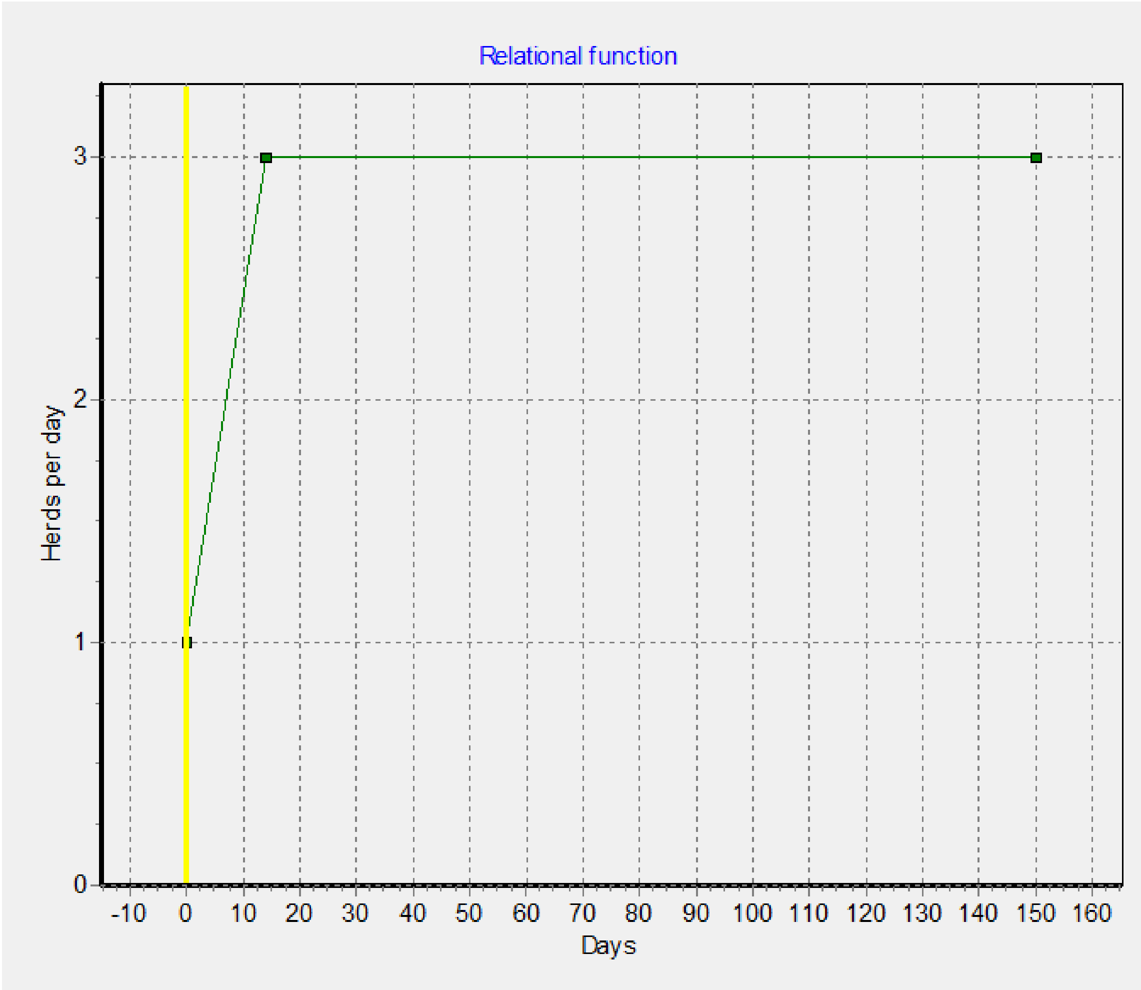

Figure A.41 Destruction Capacity

Table A.6 Destruction Priorities

Primary Reason	Secondary Reason
Reason for destruction	Detected
Production type	Direct Contact
Days holding	Circle/ring
	Indirect Contact

Destruction

Applies to all five production types: feedlot, cow-calf, swine, dairy, and sheep

Destroy detected disease units of this production type

Pre-emptively destroy units of this production type

Destroy units of this production type that have had DIRECT contact with a detected unit identified by trace surveillance

Vaccination

Vaccination was used in this simulation.

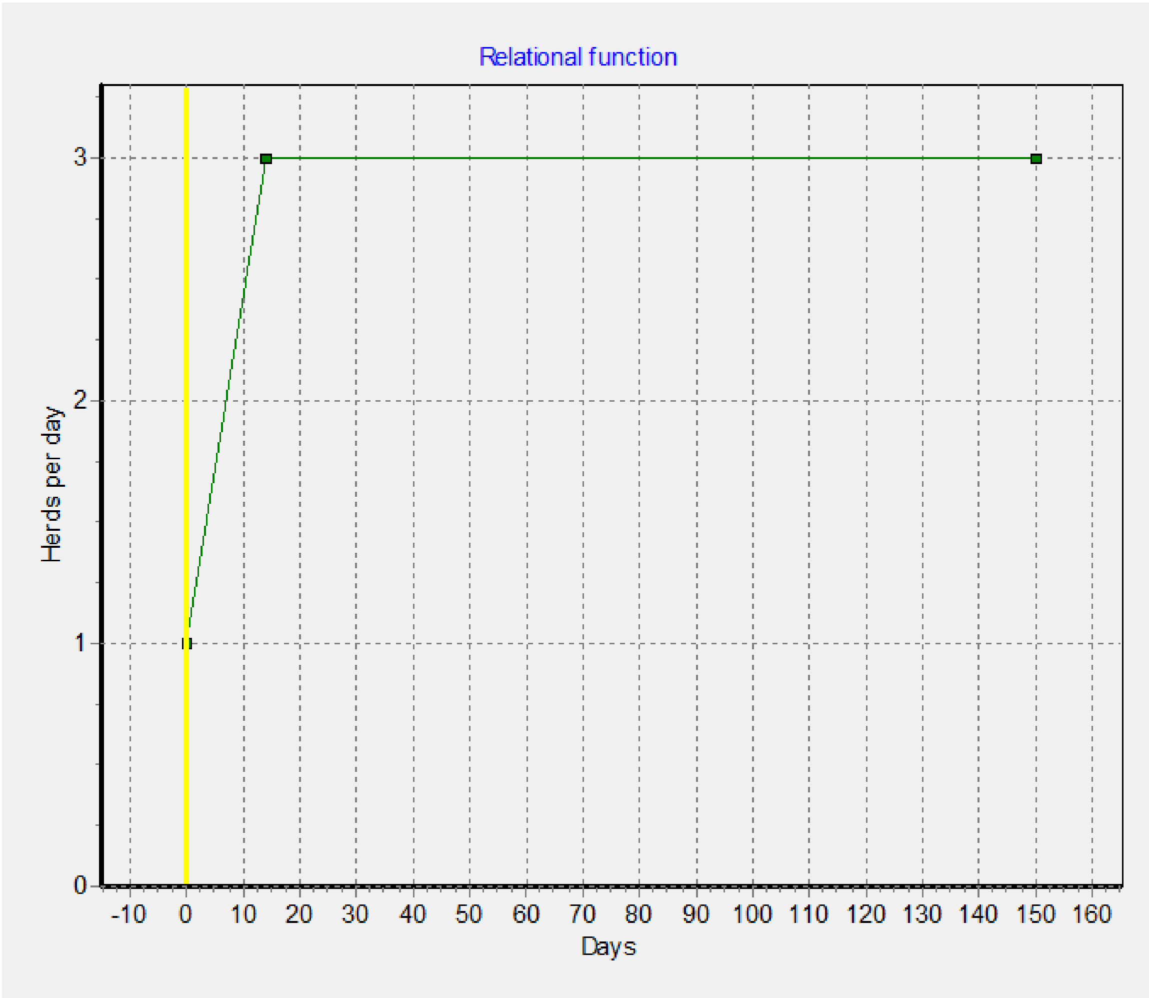

Figure A. 42 Vaccination Capacity

Table A.7 Vaccination Capacity

Primary Reason	Secondary Reason
Reason for destruction	Ring
Production type	
Days holding	

Vaccinate units of this production type as part of disease control

Delay in unit immunity following vaccination (days): 20 days

Minimum time between vaccinations (days): 90 days

Trigger a vaccination ring upon disease detection in units of this production type

Radius of vaccination ring (km): 3km

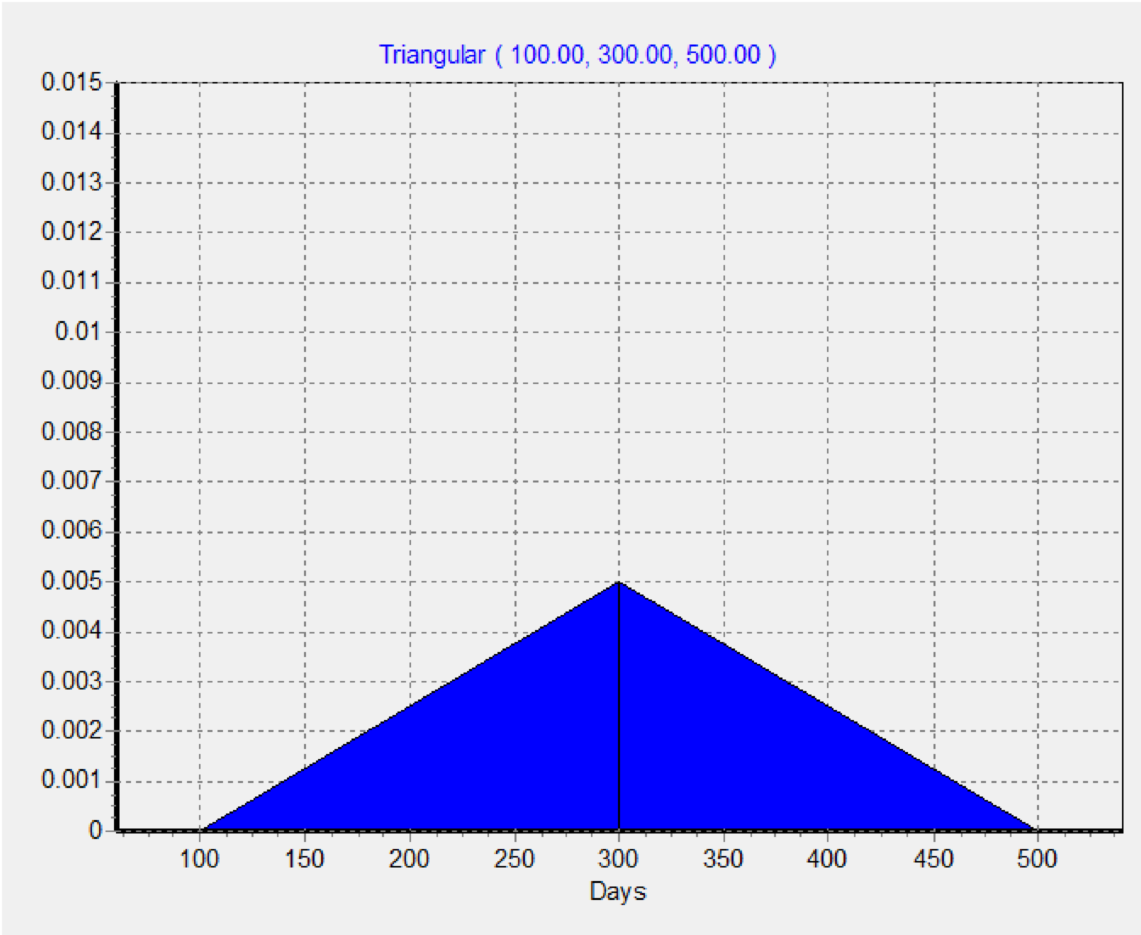

Figure A.43 Vaccine immune period (All Production Types)

Cost Accounting

Cost accounting was not used in this simulation.