ABSTRACT

An Economic Evaluation of Intervention Strategies for Porcine Epidemic Diarrhea

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The recent outbreak of PED in North America, including Ontario, highlighted the severe threat posed by this disease for the swine industry. In completely susceptible herds, there is no immunological protection in piglets to the PED virus so the mortality rate is initially very high for young pigs (almost 100%) as is the morbidity rate. However, the economic costs of a PED outbreak, including production losses and expenditures on PED-intervention strategies, remain poorly documented. A simulation model is constructed in this study to calculate the costs of a PED outbreak on an individual farrow-to-finish farm in Ontario and to estimate the reduction in these costs as compared to the expense associated with implementing alternative control and elimination practices. The results indicate that the benefits of all intervention strategies in controlling the PED outbreak, associated with the reduction in losses from the disease are greater than the costs of implementing the strategy. The most cost-effective strategy involves closing the herd and front-load gilt introduction along with average feedback effort and intensive efforts on biosecurity protocols. The net benefits to that strategy are $257,000 for a 700 sow farrow-to-finishing farm. The costs of PED are estimated to be approximately 20 per market hog.
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CHAPTER 1

INTRODUCTION

1.1 Introduction to Chapter

Chapter 1 provides an overview of the swine industry in Ontario and the impact of PED outbreak on North American swine industry. The background presented in this section provides a brief description of PED impacts on farm production and intervention measures that have been in place in North America. The economic problem and economic research problem are discussed followed by purpose and objectives of this thesis. In the end, an outline of this thesis is presented.

1.2 Background

The swine industry is a vital part of Canada’s agricultural economy. According to Canada Pork International (2014), the pork sector generated more than $2.7 billion in 2010, which took up to 30% of overall livestock trade and to 10% farm cash receipts. In 2013, Ontario was the second largest hog producer in Canada, which owned (3.1 million heads) around 25% of total pig inventories in Canada (Ontario Pork, 2013). Sales generated by Ontario hog processors were $883 million, which accounted for 3.2% market shares in North America hog market (Ontario Pork, 2014). In addition, it was estimated that Ontario swine industry contributed $523 million in total provincial GDP that is equivalent to provide 13,397 full-time jobs for whole provincial economic.

The outbreak of swine diseases can negatively affect net returns to farmers by reducing quantity (eg. increasing mortality rate) as well as quality (eg. meat color) of pig products, and
feed conversion efficiency (Bown and Davis, 2004). In addition, the presence of swine diseases can also shrink profit margins through increasing costs of control strategies (McInerney, 1996). Given those negative effects of diseases on swine industry, a potential outbreak of swine diseases can lower competitiveness of Ontario swine sector when compared with other livestock sectors within the region or other hog sectors across regions.

The recent outbreak of porcine epidemic diarrhea (PED) in the U.S. and Canada has become a concern for swine sectors in both countries. The incidence of PED can negatively impact production of affected farms by decreasing quantity and quality of outputs (Sanchez, 2014). Specifically, in completely susceptible herds affected by PED, there is no immunological protection in piglets so the mortality rate is initially very high for young pigs (almost 100%) as is the morbidity rate (Geiger and Corner, 2013). The PED outbreak in the US is estimated to have reduced swine numbers by 3% and resulted in a welfare loss of approximately $1 billion to both producers and consumers of pork (Paarlberg, 2014). In Canada, there have been 69 confirmed primary cases of PED since January 2014 with 63 in Ontario (Ontario Pork, July 2014).

The clinical effects of PED in the form of watery diarrhea, vomiting and dehydration inflicted upon susceptible animals is reasonably well understood (Puranaveja et al. 2009; Song and Park, 2012; Geiger and Corner, 2013). However, the economic costs of a PED outbreak, including production losses and expenditures on PED-intervention strategies, remain poorly documented. Veterinary practitioners implement several PED control and elimination measures with the aim to completely eradicate PED virus infection from herds. These include the breeding herd closure along with feedback exposure in all sow herds for a certain time period, the strict implementation of farm biosecurity protocols which involve applications of different sanitation protocols based on alternative disinfectants, and the use of vaccines in some situations. In
addition, diagnostic tests are performed to detect virus in the farm over time.

1.3 Economic Problem

Currently, the economic effect of PED outbreak on an individual farm is unknown due to this is a relatively new infectious disease in Ontario. As a result, despite the good understanding of PED intervention strategies, little is known about the economically best management practices for preventing and controlling PED outbreaks. Therefore, this study provided an economic estimation of costs of PED outbreak in Ontario, and evaluating the relationship between potential PED intervention strategies and disease severity, which allows for the measurement of the overall loss reduction of PED outbreak with respect to alternative intervention strategies.

1.4 Economic Research Problem

The economic costs of a livestock disease outbreak have typically been calculated through a partial-budgeting spreadsheet model, based on a basic framework described by McInerney et al. (1992). For example, Bennett et al. (1999) developed a static, partial-budgeting model to estimate the direct costs of 30 different livestock diseases in Great Britain. Within the swine sector, Meuwissen et al. (1999) used a partial-budgeting analysis framework to construct EpiLoss, which is a disease simulation model used to determine the direct costs and consequent losses attributed to a Classical Swine Fever outbreak. Similarly, Alarcon et al. (2013a) developed an epidemiological stochastic simulation model to determine the net costs of producing a diseased pig with post-weaning multi-systemic wasting syndrome (PMWS) or porcine circovirus type 2 (PCV2) subclinical infections (PCV2SI). Alarcon et al. (2013b) used these cost estimates to identify the cost-effectiveness of alternative control strategies. This is the type of analysis that
is lacking but required for PED.

Though numerous studies have been conducted on measuring the overall costs of animal disease outbreak few have addressed in a farrow-to-finishing commercial system, especially for the outbreak of PED. In addition, due to the inherently uncertain nature of the livestock infectious disease and its effects, unique courses of intervention strategies are required for a particular disease outbreak. Therefore, the economic research problem addressed by this study is what the most cost-effective practices are for an Ontario swine farmer when there is an outbreak of PED. Lack of knowledge on adopting a most cost-effective combination of control measures can raise costs of production for farmers since added inputs (eg. drugs) do not effectively convert to outputs (eg. saved pig numbers). Thus, it is crucial for swine farmers to have a good understanding of choosing the cost-effective disease intervention strategies. Additionally, approaches adopted in this study to define a most cost-effective disease intervention strategy are also applicable to addressing responses for other swine disease incidences.

1.5 Purpose and Objectives

The purpose of this study is to analyze PED control and elimination strategies for individual farrow-to-finish herds. Specific objectives include:

1. develop a conceptual framework to define net benefits of a disease intervention strategy;

2. contrast a simulation model that estimates the number of pigs by population cohort on a weekly basis for a farrow-to-finish farm based on production parameters;

3. estimate net benefits of each PED intervention strategy by empirically implementing the conceptual framework into the simulation model ;

4. determine the most cost-effective set of control and elimination measures for a PED
outbreak through the comparison of net benefits from each intervention strategy.

1.6 Outline of the Thesis

The thesis proceeds with the literature review on PED epidemiological and economic research in chapter 2, in which a more detailed description of PED clinical symptoms, transmission, and the various control and eradication measures is provided. Furthermore, the review of studies on the economic effect of PED is also included. Chapter 3 reviews the theoretical framework of disease impacts on livestock production. A simple conceptual framework is also developed in this chapter to define the net benefit of a disease intervention strategy. Chapter 4 outlines the empirical model constructed to estimate pig number by population cohorts on a weekly basis for a farrow-to-finishing herd in Ontario. Chapter 5 presents simulation results under a no disease production scenario, a base PED outbreak scenario and intervention scenarios. Additionally, the sensitivity analysis is conducted and its results are presented. Chapter 6 summarizes the study and discussed the key results. A discussion of the study’s limitation and contribution is also included.
CHAPTER 2
LITERATURE REVIEW

2 Introduction to Chapter

This chapter provides the comprehensive background on PED definition, transmission, clinical signs and its economic effects on swine farm production. An outbreak of PED on a farrow-to-finishing farm can lead to numerous piglets death and slow growth in adult pigs. Additionally, repeated outbreaks may occur in the previously affected farm due to high contaminated environment or insufficient herd immunity. The discussion of PED control and elimination measures is provided to control and eliminate a PED spread within the farm. The knowledge on epidemiological characteristics of PED provides the essential context for constructing an economic simulation model in the following chapters.

2.1 Definition of the Disease

Porcine Epidemic Diarrhea is caused by an enveloped, single-strand and positive-sense RNA virus belonging to the family Coronaviridae (Zhang et al., 2013). PED virus was first recognized in the United Kingdom in 1978, and it has spread throughout Europe and Asia (Pensaer and Bouck, 1978; Takahashi et al., 1983; Kweon et al., 1993; Thanawongnuwech et al., 2009; Chen et al., 2010). PED virus was first detected in the U.S. swine herd in 2013 and it has the high density (99%) to the strain recognized in China (Stevenson et al., 2013).

2.2 Transmission of Virus and Symptoms of Disease

The fecal-oral transmission of PED plays the most important role in spreading virus between animals (Pospischil et al., 2002). PED virus may be introduced into a naïve herd through
contaminated personnel, equipment, transportation vehicle and other fomites (Pospischil et al., 2002). There is evidence PED spread through feed contamination (Dee et al., 2014).

In a completely susceptible herd, PED can cause acute watery diarrhea, vomiting, dehydration, lack of appetite and colic or abdominal pain in all age of pigs, with initially high mortality and morbidity rate (Pospischil et al., 2002). Despite the fact that all age pigs may be affected by PED, neonatal pigs are most likely to display severe clinical signs. Specially, mortality caused by PED can be as high as 100% among pigs aged less than one week, while low mortality rate (1% to 3%) can be found among feeder and finishing pigs. In addition, PED also affects fattening performance of grow-finishing pigs by reducing the daily weights gains (Alvarez et al., 2015). In endemic herds, persistent diarrhea may occur in the newly weaned piglets due to PED (Pospischil et al., 2002).

2.3 Economic Effects of Disease

The economic effects due to PED outbreak can be substantial (Geiger and Connor, 2013; Chen et al., 2014; Jung and Saif, 2015). The economic costs of PED include production losses due to the virus and expenditures spent on intervention strategies. Production losses caused by PED can be categorized into two: 1) low reproductive performance in the breeding herd due to high pre-weaning mortality losses; 2) poor fattening performance in the feeder and finishing herds caused by additional feeding periods due to diarrhea and vomiting. Since there is no effective treatment of PED affected animals, and intervention strategies in affected herds rely on strategic measures applied to the entire population over a prolonged period of time (Geiger and Connor, 2013).

(Engele et al., 2014) estimated that PED outbreaks under an excellent and a poor
management practices in U.S. cost farmers $274 per sow and $528 per sow respectively, over a production cycle. (Paarlberg, 2014) estimated a welfare loss of approximately $1 billion to both producers and consumers of pork in U.S. based on an estimated 3% reduction of swine number due to PED.

2.4 Control and Eradication of Disease

There is no effective treatment for PED affected animals since the agent is a virus. Thus, PED control and elimination practices aim to prevent the reinfection of PED in herds through the eradication of the virus and immunization of the stock. Three specific measures are examined: (1) breeding herd closure along with the feedback exposure, (2) biosecurity improvements, and (3) vaccination.

Control of PED transmission requires the timely boosting of herd immunity. The timely breeding herd closure along with feedback exposure plays the vital role in boosting herd immunity against PED virus (Geiger and Connor, 2013; Turner, 2015). The uses of herd closure and feedback exposure have been discussed in eradicating Transmissible Gastroenteritis (TGE) virus and Porcine Reproductive & Respiratory Syndrome (PRRS) in literature (Carpenter and Templeton, 1996; Torremorell and Christianson, 2002; Corzo et al., 2010). Specifically, this is achieved by implementing immediately breeding herd closure to introduced gilts for at least 16 weeks after outbreak, while exposing the female animals to the virus with the goal to boost herd immunity.

The tightened biosecurity improvements aim to minimize the chance of virus remained in the environment and preventing the recurrence of PED outbreaks (Goede and Morrison, 2013). A complete set of biosecurity protocols of PED should include: (1) physical separation of different
rooms of the barn; (2) dedicated equipment for different rooms; (3) change of coveralls and boots between rooms; (4) limiting traffic (people and equipment) onto the farm; (5) the clearance of all organic matters; and (6) applications of different sanitation protocols based on alternative disinfectants

The PED vaccine is used as a supplementary control measure which sustains the herd immunity in the breeding herd. iPED+ vaccine developed by Harrisvaccines was the first conditional licensed PED vaccine in Canada (Farms.com, 2014). However, the efficacy of virus against infection and clinical disease remains unknown.

## 2.5 Summary to Chapter

This chapter has introduced the scientific context of PED impacts on the swine farm production. The goal of intervention strategies is to control PED transmission and eliminate the potential of continuous virus circulation which could lead to repeated outbreaks of clinical disease. Based on these contexts, chapter 3 provides a simple conceptual framework to quantify to economic losses of PED and cost-effectiveness of each intervention strategy.
CHAPTER 3

THE ECONOMICS OF ANIMAL DISEASE

3 Introduction to Chapter

Chapter 3 starts with an analytical framework adopted from Howe & McInerney (1987) to illustrate negative impacts of disease on livestock operation. Based on this framework, direct costs of the animal disease outbreak on farm production are adopted from McInerney (1996). Also, a conceptual framework that defines the net benefit of disease intervention strategy, which is the loss reduction from disease outbreak with no intervention in place, is introduced. Additionally, a brief review of modeling techniques is provided to illustrate the potential options for model construction in animal disease economics. The conceptual framework introduced in this chapter will contribute to the establishment of the empirical model in the next chapter.

3.1 Economic Impacts of Animal disease

Howe & McInerney (1987) provided a basic economic analysis framework underlies the economic activity in livestock system is to convert resources (e.g. feed, water) into a variety of products (e.g. meat, fiber) to satisfy people. Based on this conceptual framework, McInerney (1996) summarized the negative effects of animal disease on livestock production (Figure 3.1), which include:

a) decreases in basic resources (e.g. death of breeding animals);

b) reduction in the efficiency of resource conversion process (e.g. lower weight gains);

c) reductions in physical outputs or its unit value (e.g. lower meet quality);

d) extra costs on products processing (e.g. drug residues);

e) direct impact on human health (e.g. salmonella);
f) adverse impact on other parts of the economic system (eg. trade restriction).

The first three effects ((a), (b) and (c)) are the direct impacts of livestock disease which results in either increasing resource uses for a given output level of products or decreasing the value (quantity and/or quality) of products for a given level of input resources (Howe & McInerney, 1987; Rushton et al., 1999). Specifically, these impacts may be visible (eg. pre-weaning mortality losses or invisible (eg. lower weights gains). The rest three effects ((d), (e) and (f)) are indirect impacts of animal disease which reduce benefits to people due to the adverse impacts on other parts of the economic activity. These indirect impacts can be extra costs on intervention expenditures (eg. vaccines) or return foregone (eg. export/import trade restriction, consumer concern).
Figure 3.1. Economic Effects of Animal Disease in the Livestock Operation

(Source: McInerney, 1996)
Dijkhuizen et al. (1991) underlie that the extent of animal disease depends on three elements: 1) the type of disease; 2) specifics infected; and 3) the level of economic affected (Table 3.1).

There are two types of disease in the economic analysis of animal disease: enzootic and epizootic. In terms of an outbreak of enzootic disease, the incidence varies by farms but can be controlled by most of individual livestock producers. Therefore, the economic costs of enzootic disease are largely buried in individual farmers. However, if the incident rate is very high so that many livestock operations are affected, losses may be transferred to consumers due to market price adjustment caused by large impact of disease on livestock production. In case of epizootic disease outbreak, regional and/or national control and elimination programs are required to contain and eradicate contagious disease spread. The production effects of the contagious disease are significant since a large amount of animals will be infected. Therefore, with no import and/or export restrictions, unaffected producers can benefit from the temporarily rises in price due to the reduction in products. However, if the foreign trade is restricted, both infected and uninfected export-oriented producers will suffer losses due to falling price which caused by oversupply of products in domestic market.

The extent of economic losses caused by animal disease varies among different animal species. The example provided by Dijkhuizen et al. (1991) estimated that a 1% increases in production costs for a pig and poultry fattening farm in Netherland results in 15% reduction in farm income while the same production increases in the dairy sector results in 5% decreases in farm income.

Estimation of economic losses due to disease is mainly focused on direct costs, which include production losses and expenditures on treatments and preventive actions, to individual producers (McInerney, 1996; Bennett et al., 1999). Most studies estimate direct costs of disease
at the farm/herd level and aggregate each individual farm losses to a regional/national level despite potential indirect costs (eg. trade restriction, lack of consumer confidence). The accuracy of estimated losses is determined by the accessibility and accuracy of the primary data (Dijkuizen et al., 1995). However, the estimated losses may vary between similar farms in spite of sufficient data available (Ngategize & Kaneene, 1985). This is because that the effects of disease can be invisible and are often impacted by other factors (eg. nutrition intake). In addition, the short-live dimension of disease makes it very difficult to determine those effects over a certain period of time or distinguishing them from other diseases.
Table 3.1. Economic Losses Caused by Animal Disease at Different Economic Levels

<table>
<thead>
<tr>
<th>Economic Level</th>
<th>Type of Disease</th>
<th>Enzootic Disease</th>
<th>Epizootic Disease</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Generally present at farm level through different incidence rate</td>
<td>International trade restrictions</td>
</tr>
<tr>
<td>Farm</td>
<td>Direct relation between loss and degree of present of the disease per farm place</td>
<td>Large incidental losses despite whether the farm is affected or not, potentially compensated for culled animals</td>
<td>Large losses on the affected farm, potentially compensated for culled animals; advantage for not affected farms</td>
</tr>
<tr>
<td>Sector</td>
<td>Loss, if the price does not alter itself</td>
<td>Substantial losses, especially for export-oriented farms, resulting from dropping prices because of falling demand</td>
<td>Moderate losses, depending on possible compensation and on degree of price adjustment</td>
</tr>
<tr>
<td>Consumer</td>
<td>Losses due to high prices, which caused by extra costs of control strategies during the production process</td>
<td>Incidental advantage</td>
<td>Slight loss</td>
</tr>
</tbody>
</table>
3.2 Conceptual Framework

3.2.1 Modeling Disease Direct Costs

The direct impacts of disease on livestock farms can be represented by a simple production function adopted from McInerney (1996):

\[ Q = f \left( \frac{R}{\bar{N}}, \bar{K} \right) \]

where:

- \( Q \) is the flow of average output (eg. average livestock weight gain),
- \( R \) is the level of conventional variable inputs (eg. Feed, labor),
- \( \bar{N} \) is the size of the livestock herd,
- \( \bar{K} \) is the level of fixed inputs (eg. Land).

Thus, given variable resources (\( R \)) to a livestock population (\( \bar{N} \)) and the associated other fixed factors (\( \bar{K} \)), a flow of average output (\( Q \)) is produced by this livestock operation.

An animal disease outbreak can decrease the level of output by either reducing the size of livestock (\( \bar{N} \)) (eg. increasing mortality rate) or by lowering the productivity of inputs (\( R \)) (eg. lower weight gains). The disease impacts are depicted in the form of \( Q_D = f_D \left( \frac{R}{\bar{N}}, \bar{K} \right) \). Figure 3.2 presents comparison of the ‘healthy’ livestock production and the ‘diseased’ livestock production.

In addition, an input price (\( P_R \)) to output price (\( P_Q \)) ratio line is presented in order to indicate the level of variable inputs use that will maximize profits.\(^1\)

---

\(^1\) According to McInerney (1996), the level of maximized profits is achieved where the slope of production function equals to the relative prices of input (\( P_R \)) and output (\( P_Q \)): \( \frac{\partial Q}{\partial R} = \frac{P_R}{P_Q} \)
Figure 3.2. Inputs adjustments and costs of animal disease

(Source: Adapted from McInerney, 1996)
Figure 3.2 illustrates the direct impacts of an incidence of animal disease in a livestock production. Firstly, the presence of a livestock disease leads to different impacts on output losses between a low intensity system and a high intensity system (McInerney, 1996). To be more specific, the greater direct output losses can be seen under the high intensity production system \((Q_H - Q_H^D)\) by given variable inputs uses at level \((R_H)\) than losses under the low intensity operation \((Q_L - Q_L^D)\) using \((R_L)\) inputs \((R_H > R_L)\). Secondly, not only the levels of output decrease, but also the use of inputs will be altered due to disease impacts. The pre-event profit maximizing equilibrium for ‘healthy’ production function is at A, with levels of input \((R_H)\) and output \((Q_H)\). In case of a disease outbreak, the level of input use is modified to \((R_L)\), which derives output \((Q_L^D)\). Thus, the alternative profit maximizing equilibrium with the disease impacts is at D. The conventional calculation of disease costs will take account of output reductions as disease losses, which value at output prices \((Q_L - Q_L^D) \times P_Q\). However, the overall losses due to a disease outbreak should consider the impact of input alteration and calculated as: \((P_Q \times Q_H - P_R \times R_H) - (P_Q \times Q_L^D - P_R \times R_L)\) or (EF). It is possible that disease may decrease output price (eg. decrease in output quality) results in the increases of the price ratio \((P_R/P_Q)\). Therefore, input uses may reduce and increasing the extent of the losses from the disease.

### 3.2.2 The Disease Control Model

The net benefit of a disease intervention strategy is equal to the sum of the reduction in losses resulting from the intervention less the cost of its implementation. The net benefit can be expressed formally as,

\[
NB_i = LR_i - C_i
\]  

[1]

where,
\( NB_i \) is the net benefit from the disease intervention \( i, \ i = 1, 2, \ldots, n. \)

\( LR_i \) is the reduction in losses from the disease resulting from intervention \( i; \)

\( C_i \) is the cost of implementing the disease intervention \( i. \)

The occurrence of the disease without any intervention results in losses which are equal to net farm income without the disease less net returns with the disease present. Thus,

\[
L_D = \pi - \pi_D \tag{2}
\]

where,

\( L_D \) is the losses due to disease without intervention;

\( \pi \) is net farm revenue without the disease present;

\( \pi_D \) is net farm revenue with the disease present.

Note that \( L_D \) will be positive since \( \pi > \pi_D \). Similarly, the losses from the disease but with an intervention strategy are defined as:

\[
L_i = \pi - \pi_i \tag{3}
\]

where,

\( L_i \) is the losses due to disease with intervention \( i; \)

\( \pi_i \) is net farm revenue with the disease but implementing intervention strategy \( i. \)

Since using the intervention strategy reduces the impacts of the disease on farm returns \((\pi_i > \pi_D)\), then expected losses from the intervention will be less than without \((L_i < L_D)\). The reductions in losses from the disease from an intervention strategy are thus calculated as:

\[
LR_i = L_D - L_i = (\pi - \pi_D) - (\pi - \pi_i) = \pi_i - \pi_D \tag{4}
\]


\[
NB_i = \pi_i - \pi_D - C_i \tag{5}
\]

The cost-effective intervention strategy \((i^*)\) is the one that maximizes net benefits,
The next section describes how the elements of [6] are calculated.

### 3.3 Modeling Approaches

A variety of modeling approaches has been discussed in animal health economics (Dijkhuizen et al., 1995; Rushton et al., 1999). According to Dijkhuizen et al. (1995), the use of modeling approaches are determined by: 1) the characteristic of the disease; 2) the availability of resources (eg. human resources, time); and 3) the available and reliability of data on the disease impacts. It is also important to distinguish static and dynamic models as the static model does not simulate the impact of disease over time while the dynamic model considers time as a variable. Depends on the characteristic of data, a deterministic model uses definite data to estimate quantities of livestock production (eg. slaughter weights) whereas a stochastic model analyzes risks in prices and quantities with probability distributions. In addition, the distinction between optimization and simulation need to be considered based on the outcome of the modeling approach. The optimum solution is determined by an optimization model provided the objective function and restrictions. On the contrary, a simulation model estimates outcomes of different sets of input variables (eg. scenarios).

#### 3.3.1 Partial Budgeting Analysis

Partial budgeting analysis quantifies economic outcomes (eg. extra revenues or extra costs) of a specific change in livestock production (Dijkhuizen et al., 1995). Four components are examined when a change is made for a farm production: added revenues, saved costs, revenues foregone and added costs. Only if the total added benefits (added revenues and saved costs)
overpass the extra costs (revenues foregone and added costs), the change is adopted. Partial budgeting analysis probably provides the simplest economic comparison of disease control measures on a farm basis, and has a great implication in estimating economic effects of animal disease (Rushton et al., 1999). (Meuwissen et al., 1999) applied partial budgeting analysis to estimate economic losses associated with classical swine fever outbreak for affected farms, government and related industries in the production chain in Netherlands. Alarcon et al. (2013a) used partial budgeting analysis to estimate economic losses for post-weaning multi-systemic wasting syndrome (PMWS) or porcine circovirus type 2 (PCV2) subclinical infections (PCV2SI) in England. Based on the estimated costs, Alarcon et al. (2013b) identify the cost-effectiveness of alternative control strategies by adopting investment appraisal which includes a partial budgeting analysis.

3.3.2 Cost-benefit Analysis

Cost-benefit analysis is a technique to examine the profitability of pre-defined actions over a period of time. Since time plays an important role in this modeling approach, cost-benefit analysis is adopted for the long-term disease intervention program at regional or national level. Thus, costs and benefits generated by each individual alternative need to be discounted in order to make them comparable. The net present value, internal rate of return and the benefit-cost ratio are general forms of results from cost-benefit analysis. In the case of swine disease outbreak, Fasina et al. (2012) evaluated profitability of implementing biosecurity to against African swine fever in an individual farrow-to-finish farm in Nigeria.
3.3.3 Decision Analysis

In case of an epidemic disease outbreak, the actual incidence rate of the disease on a farm is difficult to predict. Therefore, if the probability of disease presents or of the outcome of proposed course of actions need to be considered, decision analysis is more favorable than partial budgeting analysis for evaluating the optimum solution (Rushton et al., 1999). Specifically, three fundamental factors need to be determined in decision analysis: (1) course of actions pre-defined by decision makers; (2) the probability of course of actions occurred; (3) the value of different outcomes. The general formats of decision analysis include pay-off table and decision-tree. Dijkhuizen et al. (1995) provided a hypothetical decision-tree example to evaluate choices of whether or not to vaccinate.

3.3.4 Mathematical Programming

The use of mathematical techniques in determining the optimum solution has been used widely in the field of animal health economics (Rushton et al., 1999) The common mathematical modeling approaches include linear programming and dynamic programming.

Linear programming is a technique that applies mathematical procedure to guarantee the optimum solution is determined. Specifically, a linear programming model includes: (1) an objective function to be maximized or minimized; (2) constraint functions which satisfy the objective; and (3) various solutions (Heady & Chandler, 1958). In animal health economics, linear programming is most extensively at the farm level. For instance, Habtemariam et al. (1984) evaluate the economics of control strategies for trypanosomosis in Ethiopia using linear programming.

Dynamic programming uses mathematical technique to evaluate the set of decisions (eg.
expressed in a decision-tree) that maximize economic benefits or minimize economic losses. The application of dynamic programming in supporting the swine breeding herd management can be found in Huirne (1990).

3.3.5 Systems Simulation

The use of systems simulation requires the creation of a mathematical model to depict the system under consideration (Dijkhuizen et al., 1995). The simulation model reflects real-world situations in an explicit mathematical fashion and can be altered by input adjustment. Systems simulation is frequently applied at the herd level animal disease analysis since computer-based simulation models are capable to deal with very complex situations which may be found in costly and time-consuming field trials (Dijkhuizen et al., 1995). One important advantage by using systems simulation is the implication of sensitivity analysis, in which values of significant parameters are modified over a range of interest in order to examine their impacts on results. Meuwissen et al. (1999) constructed a disease simulation model EpiLoss to determine the direct costs and consequent losses attributed to a Classical Swine Fever outbreak.

3.4 Summary to Chapter

Chapter 3 introduces a conventional conceptual framework that quantifies the animal disease impacts on livestock operation. This is the foundation of establishing the empirical model. In addition, a conceptual model of defining the net benefit of disease intervention strategies is discussed in this chapter. This foundation of knowledge shows the effectiveness of intervention strategy on reducing the direct economic losses of PED outbreak. In the end, several modeling techniques are discussed in this chapter. The conceptual frameworks and modeling techniques
discussed in this chapter provide foundation of the empirical model that established in the next chapter.
CHAPTER 4
EMPIRICAL FRAMEWORK

4 Introduction to Chapter

This chapter introduces the empirical framework used in this analysis. A simulation model is constructed based on the conventional conceptual framework introduced in the previous chapter to estimate the production (pig inventories and slaughter weights) of a farrow-to-finishing farm. The conceptual framework that defines the net benefit of intervention strategies of PED together with a concept of severity index is used to determine the loss reduction of PED outbreak of each intervention strategy.

4.1 Base Empirical Model

A production simulation model was constructed to estimate the number of pigs by population cohorts on a weekly basis for a farrow-to-finish farm (Fig.4.1). Given the impacts of a PED outbreak vary weekly over the course of its epidemic, the model is constructed on a week-by-week basis to track the resulting changes in production and net returns. The weekly numbers are estimated for the breeding herd and the grow-finishing herd over a year.
Based on the simulation model results, the number of nursing piglets during the first week of PED outbreak is:

\[344 + 334 + 327 = 1005\]

Figure 4.1 Farrow-to-finish Herd Operation
A commercial farrow-to-finishing system needs to maintain an appropriate number of female animals targeted to be bred and are able to gestate (estimated to be bred). Thus, the starting point for the model is the target number of sows bred in the first week (Figure 4.2). For a 700 sow herd with an overall productivity of 2.35 liters annually and an 85% farrowing rate, the target number of sows bred each week is 38 (=the total number of sow*litter per sow per year/farrowing rate/52weeks/breeding interval (1week)). Given a 42% annual replacement rate for female animals, the target number of gilts bred is 7 (=the target number of sow bred*sow replacement rate/litter per sow per year). Thus, the estimated number of sows bred is 31 (=the target number of sow bred – the estimated number of gilt bred). Consequently, by taking account of farrowing rate (85%), the number of gilts and sows farrowed per week is 6 and 26 respectively. The weekly number of culled animals is equal to the weekly number of gilts and multi-parous sows that failed to farrowed.

The resulting number of sows and gilts bred will give birth during the last week of gestation with the total number of piglets born based on production parameters such as number born alive per sow (12 piglets) or gilt (11 piglets) per week, which are listed in Table 4.1 and based on averages in Ontario (OMAFRA, 2011-2014). The number of piglets nursing on the sows in each week of the 3-week lactation period is adjusted downward according to the pre-weaning mortality rates (Figure 4.3). A 13% pre-weaning mortality rate consists of 8% mortality rate for piglets aged between 0 and 1 weeks, 3% mortality rate for piglets aged between 1 and 2 weeks and 2% mortality rate for piglets aged between 2 and 3 weeks. The model tracks the weekly number of piglets moving to the nursery stage after accounting for pre-weaning mortality losses.

---

2 The target number of gilt bred is same as the estimated number of gilt bred.
3 The estimated number sow/gilt bred*farrowing rate.
4 The estimated number of gilt bred (16 weeks ago) *(1-farrowing rate) + the estimated number sow and gilt bred)*(1-farrowing rate).
5 The production cycle for a sow/gilt includes 20 weeks: 1 weeks between weaning and bred, 16 weeks in gestation and 3 weeks in lactation.
(Figure 4.4). The total of 4% nursery mortality rate is decomposed into 0.5% per week in the 8-week nursery stage. Similarly, the 6% mortality rate in the grow-finishing stage is divided into 0.375% for each week. Therefore, the weekly number of feeder pigs moved from nursery into the grow-finishing stage is also calculated (Figure 4.5). For example, given the growth performance measures in Table 4.1, 296 finishing pigs with a dressed carcass weight of 98 kg per hog are produced each week.

The sale of the market hogs (296 heads weekly or 15,392 heads annually) is the main source of income to the hypothetical farm. The market price for hogs has fluctuated dramatically over the last 10 years from the lows of 2009 to recent peak prices in 2014, with some of price increases due to the effects of PED (Statistic Canada, 2014; Grier, 2014; Ignjatovic, 2014). Using a base selling price of $172 per 100kg of dressed carcass weight for a market hog at index 110, which is calculated upon a four-year average from 2011 to 2014, total annual revenue for the farm is $2,936,959.

Feed is the largest component of production costs in swine sector. Annual feed costs were based on the four-year (2011-2014) average costs of $123.10 per finisher which comprised of feed costs on the sow of $17.19, on the feeder pig of $16.79 and on the finishing pig of $89.12. Therefore, on the weekly basis, the adjusted average feed costs are $7.77 on the sow, $2.10 on the feeder pig and $5.57 on the finisher (Table 4.1). The net replacement costs of gilt are assumed to be the gilt purchase value, which is calculated as the market hog value plus $130, minus cull sow value that equals to market hog value minus $30. The feed and replacement costs are deducted from revenue to determine net returns to fixed assets or \( \pi \) in equations 2, 3 and 4.
Table 4.1 Production Parameters of the Farrow-to-finish Swine Farm Production

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Breeding Herd Performance</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sow Number</td>
<td>700</td>
<td>Assumed</td>
</tr>
<tr>
<td>Litter per Sow per Year (Times)</td>
<td>2.35</td>
<td>(OMAFRA, 2011-2014)</td>
</tr>
<tr>
<td>Farrowing Rate (%)</td>
<td>85</td>
<td>(OMAFRA, 2011-2014)</td>
</tr>
<tr>
<td>Sow Replacement Rate (%)</td>
<td>42</td>
<td>(OMAFRA, 2011-2014)</td>
</tr>
<tr>
<td>Pre-weaning Mortality Rate (%)</td>
<td>13</td>
<td>(OMAFRA, 2011-2014)</td>
</tr>
<tr>
<td>Breeding Interval between Batches of Sows (Week)</td>
<td>1</td>
<td>(OMAFRA, 2011-2014)</td>
</tr>
<tr>
<td>Number of Piglets Born Alive per Litter per Gilt/multi-porous Sow</td>
<td>11/12</td>
<td>(OMAFRA, 2011-2014)</td>
</tr>
<tr>
<td><strong>Growing Herd Performance</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nursery Mortality Rate (%)</td>
<td>4</td>
<td>(OMAFRA, 2011-2014)</td>
</tr>
<tr>
<td>Finishing Mortality Rate (%)</td>
<td>6</td>
<td>(OMAFRA, 2011-2014)</td>
</tr>
<tr>
<td><strong>PED Impacted Parameters</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farrowing Rate (%)</td>
<td>80</td>
<td>Goede and Morrison (2013)</td>
</tr>
<tr>
<td>Pre-weaning Mortality Rate (%)</td>
<td>13-100</td>
<td>(Provis, 2014)</td>
</tr>
<tr>
<td>Mortality Rate on Early Weaned Group (%)</td>
<td>50</td>
<td>Assumed</td>
</tr>
<tr>
<td>Finishing Mortality Rate (%)</td>
<td>16</td>
<td>Alvarez et al. (2015)</td>
</tr>
<tr>
<td>Added Finishing Period (week)</td>
<td>1</td>
<td>(Provis, 2014)</td>
</tr>
<tr>
<td><strong>Incomes from Market Hog (per hog)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base Formula Price for Pork ($/ckg)</td>
<td>173.37</td>
<td>(OMAFRA, 2011-2014)</td>
</tr>
<tr>
<td>Average Dressed Weight (kg/hog)</td>
<td>98.02</td>
<td>(OMAFRA, 2011-2014)</td>
</tr>
<tr>
<td><strong>Costs of Swine Production (Average)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sow Feed Costs per Pig ($)</td>
<td>17.19</td>
<td>(OMAFRA, 2011-2014)</td>
</tr>
<tr>
<td>Nursery Feed Costs per Pig($)</td>
<td>16.79</td>
<td>(OMAFRA, 2011-2014)</td>
</tr>
<tr>
<td>Finishing Feed Costs per Pig($)</td>
<td>89.12</td>
<td>(OMAFRA, 2011-2014)</td>
</tr>
<tr>
<td>Adjusted Feed Costs per Sow per Week&lt;sup&gt;6&lt;/sup&gt;</td>
<td>7.77</td>
<td></td>
</tr>
<tr>
<td>Adjusted Feed Costs per Feeder Pig per Week&lt;sup&gt;7&lt;/sup&gt;</td>
<td>2.10</td>
<td></td>
</tr>
<tr>
<td>Adjusted Feed Costs per Finisher per Week&lt;sup&gt;9&lt;/sup&gt;</td>
<td>5.57</td>
<td></td>
</tr>
<tr>
<td>Other Variable Costs per Pig($)&lt;sup&gt;10&lt;/sup&gt;</td>
<td>0.77</td>
<td>(OMAFRA, 2011-2014)</td>
</tr>
<tr>
<td>Fixed Costs per Pig($)&lt;sup&gt;11&lt;/sup&gt;</td>
<td>0.45</td>
<td>(OMAFRA, 2011-2014)</td>
</tr>
</tbody>
</table>

<sup>6</sup> ckg stands for 100kg.

<sup>7</sup> According to Notes for Swine Budget (OMAFAR, 2011-2014), “The Farrow to Finish Budget is the accumulated cost of the three phases (Farrow to Wean, Nursery, and Grow-Finish) and is based on 23.25 market pigs sold per sow per year”, the average feed costs per sow per week is: 17.19*23.25/52=$7.77.

<sup>8</sup> According to Notes for Swine Budget (OMAFAR, 2011-2014), the feeder pig spends 8 weeks in nursery phases, thus, the average feed costs per feeder pig per week is: 16.79/8=$2.10

<sup>9</sup> According to Notes for Swine Budget (OMAFAR, 2011-2014), the finisher spends 16 weeks in grow-finishing phases, thus, the average feed costs per finisher per week is: 89.12/16=$5.57

<sup>10</sup> The average non-feed variable costs include services on health, breeding, marketing, utilities, maintenance, labor, loan interest and miscellaneous (OMAFAR, 2011-2014).

<sup>11</sup> The average fixed costs include depreciation, interest, tax and insurance (OMAFAR, 2011-2014).
Figure 4.2 Pig Flows in the Breeding Herd

The yellow part illustrates pig flows in the breeding herd under the pre-disease base scenario. Given 700 sows, the total of 7 gilts and 37 sows are targeted to be bred. Therefore, the estimated number of multi-parous sows bred is 31 (=the target number of sow bred – the estimated number of gilt bred). Consequently, by taking account of 85% farrowing rate, the number of gilts and multi-parous sows farrowed per week is 6 and 26 respectively. The weekly number of culled animals is equal to the weekly number of gilts introduced from external providers (7 heads).

The pink part illustrates pig flows in the breeding herd under the PED base outbreak scenario. The 16-week breeding herd closure is implemented immediately after a PED outbreak is confirmed. Therefore, there is no introduction of gilts to the herd over the first 16 weeks. After herd reopens, the number of introduced gilts will be double over the next 16 weeks in order to bring back sow inventories to the pre-event level.
Figure 4.3 Pig Flows in the Nursing House

The yellow part illustrates pig flows in the nursing stage under the pre-disease base scenario. Given the number of piglets born alive per gilts/multi-parous sows, the breeding herd gives birth to 374 piglets per week. By taking account of weekly pre-weaning mortality rate for different ages of piglets, the number of weekly weaned piglets is 327.

The pink part illustrates pig flows in the nursing stage under the PED base outbreak scenario. The high pre-weaning mortality rate due to PED is assumed to have same effects on all piglets. Therefore, there is no survived piglet over the 10 weeks of 100% pre-weaning mortality rate.
The yellow part illustrates pig flows in nursery stage under the pre-disease base scenario. The 4% nursery mortality rate decomposed into the 0.5% weekly mortality rate for feeder pigs over 8-week period. The beginning number of feeder pigs is equal to the weekly flows of weaned piglets moved to nursery house after taking account of nursery mortality rate. The estimated weekly flows of feeder pigs moved to the grow-finishing house are 314.

The pink part illustrates pig flows in nursery stage under the PED base outbreak scenario. It is important to note that the 50% mortality losses are accounted for those early weaned piglets when they are moved to the nursery house (502 heads).
Figure 4.5 Pig Flows in the Grow-finishing House

The yellow part illustrates pig flows in grow-finishing stage under the pre-disease base scenario. The 6% nursery mortality rate decomposed into the 0.4% weekly mortality rate for finishing pigs over 16-week period. The beginning number of feeder pigs is equal to the weekly flows of weaned piglets moved to nursery house after taking account of finishing mortality rate. The estimated weekly flows of finishers sent to market are 295.

The pink part illustrates pig flows in grow-finishing stage under the PED base outbreak scenario. It is important to note that the 16% mortality losses are accounted for those early weaned piglets when they are moved to the grow-finishing house (410 heads). Additionally,
4.2 PED Base Outbreak

An outbreak of PED results in losses of $L_D$, which consists of production losses to the breeding herd (pre-weaning mortality losses) and to the growing herd (extra time spent in grow-finishing stage). In addition, the initial affected farm may suffer the reoccurrence of PED outbreaks with no interventions implemented (Goede and Morrison, 2013). In order to evaluate the cost-effectiveness of intervention strategies for the disease, the impacts of PED without interventions must be calculated, which is $\pi_D$ in equations 2, 4, 5 and 6.

It is assumed under the base PED scenario that an outbreak of PED is followed by a second outbreak within the year if the only response to the disease is closing the sow herd with no purchase of replacement gilts. The sow herd inventories will gradually return to the pre-event level through doubling the weekly number introduced gilts (12 heads) after the herd reopened (Figure 4.2). The impact of the first PED outbreak on the weekly time path for the pre-weaning mortality rate is illustrated in Figure 4.6 (Provis, Elanco Animal Health, winter 2014). The initial incidence of PED causes pre-weaning mortality to rise from the typical 13% to 50% in the first week followed by 7 weeks of 100% mortality and then falling over the subsequent two weeks to the pre-event rate of 13%. The weekly pre-weaning mortality rates for different aged nursing piglets are assumed to be same since young pigs are most vulnerable to the virus.
Based on the poor management condition (Provis, Elanco Animal Health, winter 2014), the pre-weaning mortality rate can be as high as 50% in the first outbreak week and 100% mortality rate for 2 to 8 weeks. It took almost 11 weeks to return to normal production with 13% pre-weaning mortality rate.

The pre-weaning mortality rate for the second outbreak is assumed less severe than the one in the initial outbreak. This is because that the majority of pigs may be exposed to virus due to the high presence of virus in the herd in the first outbreak, which may boost the herd immunity in the infected herd and result in some degree of herd protection.

Source: Provis, Elanco Animal Health (winter 2014)
In addition to the initial high pre-weaning mortality rate among newborn piglets, the PED outbreak also affects breeding herd performance. Goede and Morrison (2013) estimate the farrowing rate drops by as much as 12.6% and so the onset of PED is assumed to decrease the farrowing rate from 85% to 80% for 10 weeks. Litter size declines by 2 for sows and gilts so the number of piglets born alive under a PED outbreak is 10 for sows and 9 for gilts (Provis, Elanco Animal Health, winter 2014).

Although the major impact of PED is on pre-weaning mortality, it also affects feeder pigs and finishing pigs. The diarrhea and vomiting caused by PED can increase the length of time to finish a hog by one week (Engele et al., 2014). The mortality rate attributed to PED has been examined by Alvarez et al. (2015) with 14.9% for feeder pigs and 15.5% for finishers. In this study, the mortality losses due to PED in older pigs are considered for the early weaned piglets moved into nursery barn. Since those piglets have no inherent resistance to virus. Similarly, the 15.5% finishing mortality rate are accounted once for the group entering finishing barn.

The recurrence of a PED outbreak leads to reproductive failure for the breeding herd (eg. repeated pre-weaning mortality losses) and growth reduction for the finishing pigs. It is assumed that, the second outbreak, which occurs 1 week after the breeding herd re-opens, lasts a total of 7 weeks as opposed to 10 weeks with the first outbreak with 4 consecutive weeks of a pre-weaning rate of 50% (Fig.2). Furthermore, it is assumed that the farrowing rate decreases to 80%, and the number of piglets born per litter per sow/gilt down to 10/9 respectively, over the 10-week outbreak period. In addition to the repeated infection of PED on the farm, it takes a longer period for the breeding herd to return to its pre-event production since the number of sows is culled substantially during the herd closure. The replacement gilts are not introduced to the herd until it reopens. The mortality losses for feeder pigs and finishing pigs are negligible for the second

4.3 Net Returns to Intervention Strategies ($\pi_i$)

The extent to which intervention strategies reduce the impact of PED is calculated through the use of a severity index ($SI$), which expresses the reduction in losses as a percentage of the losses of the base PED outbreak with no intervention as described in the above sub-section. The value of the severity index ranges between 0 and 1, with 0 indicating all losses are eliminated while 1 represents the base PED outbreak implying the intervention is ineffective in reducing losses from PED.

An intervention can reduce the impact of PED through either reducing the probability of the PED virus being present in the herd ($PV$) or reducing the proportion of susceptible sows in the herd ($PS$). Thus, the severity index for an intervention strategy $i$ is given by

$$ SI_i = PV_i PS_i $$

The severity index indicates the reduction in the losses from the base PED scenario so that the loss reduction for intervention $i$ ($LR_i$) given by [4] can also be expressed as

$$ LR_i = L_D - L_i = L_D - L_D SI_i = (1 - SI_i) L_D $$

Note that if the intervention either eliminates the probability of the PED virus ($PV=0$) or results in complete immunity of the herd ($PS=0$), then the severity index is also equal to 0 and the loss reduction from the practice is equal to the losses from the base PED scenario with no intervention.

Since the base PED case assumes there is a second outbreak after the first outbreak (see section 3.3), the severity index is calculated for each outbreak. Thus, the severity index is decomposed into the first ($t=1$) and second ($t=2$) incidence
\[ SI_{t,i} = PV_{t,i}PS_{t,i} \quad (t=1, 2) \]  

with the loss reduction correspondingly calculated as

\[ LR_i = (1 - SI_{t,1})L_{D,1} + (1 - SI_{t,2})L_{D,2} \]  

Some strategies may result in a reduction of the losses from the first outbreak and no subsequent losses thereafter, while a second onset of PED may occur with other strategies but at reduced losses. Given the associated implementation expenditures, the net returns to the intervention strategy calculated as

\[ NB_i = (1 - SI_{t,1})L_{D,1} + (1 - SI_{t,2})L_{D,2} - C_i \]

The values for the probability of the PED virus being present in the herd \( (PV) \) and the proportion of susceptible sows \( (PS) \) in the herd for the first and second outbreaks of PED for each intervention are discussed in the next section that defines the control and elimination measures.

### 4.4 PED Control and Elimination Measures

There is no effective treatment for PED affected animals since the agent is a virus. Thus, PED control and elimination practices aim to prevent the reinfection of PED in herds through the eradication of the virus and immunization of the stock. Three specific measures are examined: (1) breeding herd closure along with the feedback exposure, (2) biosecurity improvements, and (3) vaccination. There are two options with each of the three measures good and average. It is assumed that the good option in (2) reduces the probability of the virus being present and the good option in (1), (3) decreases the proportion of susceptible sows in the herd. Each of these measures is described below including its implementation costs (Table 4.2) and the effect on production parameters (Table 4.3).
Table 4.2 Implementation Expenditures of Intervention Measures

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
<th>Sources/Note</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intervention Expenditures</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Workers$^{12}$</td>
<td>6</td>
<td>(OMAFRA, 2011-2014)</td>
</tr>
<tr>
<td>Average Wage per Hour per Worker($)</td>
<td>16</td>
<td>(Marchand and McEwan, 2004)</td>
</tr>
<tr>
<td>Costs of Feedback</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hours Required for One-time Feedback(hour)</td>
<td>8</td>
<td>Assumed</td>
</tr>
<tr>
<td>Total Costs of Feedback($)</td>
<td>768</td>
<td>16<em>6</em>8</td>
</tr>
<tr>
<td>Costs of Washing &amp; Disinfecting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Hours Required for Washing &amp; Disinfecting$^{13}$</td>
<td>128</td>
<td>Assumed</td>
</tr>
<tr>
<td>Costs of Materials for One-time Washing &amp; Disinfecting($)$^{14}$</td>
<td>738</td>
<td>(Hog Slat, 2015)</td>
</tr>
<tr>
<td>Costs of Utilities for One-time Cleaning ($)</td>
<td>400</td>
<td>Assume</td>
</tr>
<tr>
<td>Total Costs of Washing &amp; Disinfection</td>
<td>13,428</td>
<td>738+400+128<em>16</em>6</td>
</tr>
<tr>
<td>Costs of Vaccination</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vaccination Costs per Dose ($)</td>
<td>3</td>
<td>(Farms.com, 2014)</td>
</tr>
<tr>
<td>Vaccination Dose Usage</td>
<td>2</td>
<td>(Farms.com, 2014)</td>
</tr>
<tr>
<td>Total Number of Female Animals Farrowed over 52 weeks$^{15}$</td>
<td>1,582</td>
<td></td>
</tr>
<tr>
<td>Hours Required for One-time Vaccination(hour)</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Total Costs of Vaccination ($)</td>
<td>11,028</td>
<td>3<em>2</em>1582+16<em>8</em>2*6</td>
</tr>
</tbody>
</table>

$^{12}$ The number of workers for a farrow-to-finishing operation is based on 300 sows per person and 4,000 feeder pigs and finishers per person (OMAFRA, 2011-2014).

$^{13}$ 16 weeks of herd closure * extra 8 hours per week = 128 hours

$^{14}$ $30 per pair of boots, $14 per disposable coveralls and $35 per bottle of Synergize Cool™ (Hog Slat, 2015)

$^{15}$ According to simulation results (Figure 5.1)
Table 4.3 Probabilities of PED Virus Being Present and Proportion of Susceptible Sows for Different Intervention Practices

<table>
<thead>
<tr>
<th>PED Intervention Practices</th>
<th>Options</th>
<th>Effects on Probabilities of Virus Being Present and Proportion of Susceptible Sows</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$PV$</td>
</tr>
<tr>
<td>Herd Closure</td>
<td>Front</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Back</td>
<td>0</td>
</tr>
<tr>
<td>Feedback</td>
<td>Good</td>
<td>+0.2</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>+0.1</td>
</tr>
<tr>
<td>Biosecurity</td>
<td>Intense</td>
<td>-0.6</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>-0.3</td>
</tr>
<tr>
<td>Vaccination</td>
<td>Yes</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>0</td>
</tr>
</tbody>
</table>
4.4.1 Breeding Herd Closure along with the Feedback

The timely closure of the breeding herd combined with feedback exposure plays a vital role in boosting herd immunity against PED virus (Geiger and Connor, 2013; Turner, 2015). The effectiveness of this practice has been discussed in eradicating Transmissible Gastroenteritis (TGE) virus and Porcine Reproductive & Respiratory Syndrome (PRRS)(Carpenter and Templeton, 1996; Torremorell and Christianson, 2002; Corzo et al., 2010). The practice involves closing the breeding herd to replacement gilts for at least 16 weeks after the virus is detected on the farm. In addition, intestinal tissue and/or feces homogenate from diseased piglets is distributed to exposure female animals through mixing with feed, applying to feed and water areas, delivering with a water device, or spraying or squirting on/in nose or mouth during the herd closure period (Turner, 2015).

With a PED outbreak, it is assumed the breeding herd is also closed for 16 weeks after virus detection on the farm. Given that 7 sows are culled weekly for a 700-sow herd during normal production (see section 3.2), 112 gilts will be introduced either immediately prior to closing the herd (front-load) or at the end of the 16 weeks after the herd re-opens (back-load). The sero-negative gilts purchased prior to the herd closure are fully exposed to the PED virus, which ensures a high probability of complete herd immunity. The likelihood of immunity developing for gilts introduced at the back-end of the herd closure is less than with the front-load strategy as newly introduced gilts are naïve animals and may be susceptible to virus. Another cost with the back-end strategy is the reduction in revenues due to the steady decline in the sow herd that cannot be replaced for the 16-week period.

While the base PED base outbreak assumes a closure of the sow herd, there is no specific feedback practice employed and herd immunity is assumed to occur naturally through exposure
to shedding animals. In contrast, we assume two feedback exposure options adopted in intervention strategies: good and average. A good feedback exposure strategy requires exposing all adult pigs to the virus for three times, while a one-time exposure is considered as an average strategy. Each option uses feces of diseased animals and is delivered with feed and water. A one-time exposure requires an 8 additional hours of all labour employed on the farm. Given the wage rate of $16 per hour and a total of 6 workers in the farm, the one-time feedback practice costs $768. Therefore, a good feedback option, which implements feedback three times, costs $2,304.

The timely herd closure and immediate feedback exposure can boost the effective herd immunity after a PED outbreak and reduce the proportion of susceptible sows. In the U.S., the immediate closure of the sow herd with repeated feedback exposure achieved a success rate of 65% in producing negative female animals (Connor, 2013). We assume the implementation of front loading sero-negative gilts and a good feedback practice each reduce the proportion of susceptible sows by 30% so that using both practices together results in a 60% reduction. In contrast, the back-end purchase and an average feedback effort each reduces the proportion of susceptible sown by 10%. The implementation of feedback on the farm can lead to higher environmental contamination due to the repeated virus exposure. Therefore, the probability of the virus being present is assumed to increase by 5% when using the more extensive feedback option and 15% with the average feedback effort.

4.4.2 Biosecurity Protocols

A complete set of biosecurity protocols of PED should include: (1) physical separation of different rooms of the barn; (2) dedicated equipment for different rooms and between different
areas within the farm; (3) limiting traffic (people and equipment) onto the farm; (4) the clearance of all organic matters; (5) change of coveralls and boots between rooms and (6) applications of different sanitation protocols based on alternative disinfectants. Since most Ontario swine operations regularly use the first three biosecurity protocols, these are assumed for the base PED outbreak scenario. Two alternative biosecurity options are considered after a PED outbreak: (1) intensive; and (2) average. The two options are differentiated by the level of clean-up and methods of sanitation. The intensive option employs white wash as well as agricultural lime in cleaning barns, and Synergize Cool™ in disinfecting equipment and pens. Additionally, two extra pairs of boots and coveralls as well as one bottle of Lysol are purchased for each worker. Furthermore, drying and heating are used for 8 hours after clean-up and disinfection. Therefore, expenditures associated with the biosecurity improvements include 8-hour additional labor costs for six workers over 16 weeks, $738 in all materials and $400 in overall utility costs (Table 4.2). The intensive cleaning and washing will be implemented once per week during the herd closure period for the empty barns, which results from no surviving piglets due to high pre-weaning mortality losses. The regular cleaning and sanitizing are considered for the average biosecurity option so that there are no extra costs.

The thorough cleaning and disinfecting animal housing minimizes the chance of virus remained in the environment and preventing the recurrence of PED outbreaks (Goede and Morrison, 2013). Thus, we assume that the use of intensive biosecurity improvements lowers the probability of the virus being present after the initial outbreak by 60% while an average biosecurity effort reduces the likelihood of the virus present by 30%. 
4.4.3 Vaccination

The PED vaccine is used as a supplementary control measure which sustains the herd immunity in the breeding herd. iPED+ vaccine developed by Harrisvaccines was the first conditional licensed PED vaccine in Canada (Farms.com, 2014). One dose of vaccine is injected in female animals 1 to 2 weeks before farrowing, and a second booster vaccination is given prior to farrowing. The vaccination costs $3 per dose in Ontario. It takes approximately 8 hours to vaccinate all individual female animals with one dose. The number of female animals received vaccination includes farrowed gilts and multi-parous sows over the 52 weeks. Therefore, given the added 16-hour labor costs for all workers and vaccine expenditures, the overall costs of vaccination are $11,029. Vaccination performed in sow groups stabilizes herd immunity, and improving the farrowing performance of breeding herd in the PED base outbreak. However, the efficacy of vaccine in generating antibodies in female pigs remains unknown (Harris, Teleconference January 2014). We assume that the implementation of vaccination contributes to an effort with 20% sows are immunized.

4.4.4 PED Intervention Strategies

The three PED control and elimination measures discussed in the previous section can be used in combination with each other. The implementation of herd closure with good feedback and vaccination are assumed to increase the likelihood of immunity (decrease $PS_{t,i}$) and the adoption of enhanced biosecurity protocols is assumed to decrease the probability of the virus being present (decrease $PV_{t,i}$) (Table 4.3). The effectiveness of a PED intervention strategy on disease control and eradication comprises the accumulated effect of measures it employed. It is

---

16 The model gives the number of farrowed animals over 52 weeks is 1,582.
also important to note that the effect of the intervention strategy on reducing probability of virus being present and proportion of susceptible sows cannot be over 100% or less than 0%. There are two options associated with four practices (gilt introduction, feedback, biosecurity and vaccination), a total of 16 possible strategies are considered where a strategy is defined as a combination of four practices. A complete listing of the strategies along with its effects on the probability of virus being present and the proportion of susceptible sows for both the first and second PED outbreak are listed in Table 4.4.
Table 4.4 Definition of PED Intervention Strategies

<table>
<thead>
<tr>
<th>Strategies (i)</th>
<th>Description $^{17}$</th>
<th>Effects on PED Control &amp; Elimination</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gilt Intro.</td>
<td>Feedback</td>
</tr>
<tr>
<td>1</td>
<td>Front</td>
<td>Good</td>
</tr>
<tr>
<td>2</td>
<td>Front</td>
<td>Good</td>
</tr>
<tr>
<td>3</td>
<td>Front</td>
<td>Good</td>
</tr>
<tr>
<td>4</td>
<td>Front</td>
<td>Good</td>
</tr>
<tr>
<td>5</td>
<td>Front</td>
<td>Average</td>
</tr>
<tr>
<td>6</td>
<td>Front</td>
<td>Average</td>
</tr>
<tr>
<td>7</td>
<td>Front</td>
<td>Average</td>
</tr>
<tr>
<td>8</td>
<td>Front</td>
<td>Average</td>
</tr>
<tr>
<td>9</td>
<td>Back</td>
<td>Good</td>
</tr>
<tr>
<td>10</td>
<td>Back</td>
<td>Good</td>
</tr>
<tr>
<td>11</td>
<td>Back</td>
<td>Good</td>
</tr>
<tr>
<td>12</td>
<td>Back</td>
<td>Good</td>
</tr>
<tr>
<td>13</td>
<td>Back</td>
<td>Average</td>
</tr>
<tr>
<td>14</td>
<td>Back</td>
<td>Average</td>
</tr>
<tr>
<td>15</td>
<td>Back</td>
<td>Average</td>
</tr>
<tr>
<td>16</td>
<td>Back</td>
<td>Average</td>
</tr>
</tbody>
</table>

$^{17}$ Gilt Intro. stands for gilt introduction, Bios. stands for biosecurity, Vacc. stands for vaccination.

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The most effective strategy (strategy 1) is listed first and contains the most comprehensive options of each measure with excellent effect on boosting herd immunity, eradicating virus in the farm and sustaining herd immunity. In contrast, strategy 16 is the least comprehensive option for each measure with poorest performance in all three aspects. Specifically, when strategy 1 is implemented, the combination of front-load gilt introduction along with the good feedback and vaccination contributes to a 60% (\(=20%+20%+20\%\)) reduction in proportion of sows susceptible to the virus. Despite a 30% increase in the probability of virus being present due to the adoption of the good feedback practice, the intensive use of cleaning and washing decreases the likelihood of virus being present by 30% (\(=60\%-30\%\)). Therefore, the implementation of strategy 1 reduces the proportion of sows susceptible from 40% in the first outbreak to 0% in the second outbreak, and the probability of virus being present from 60% to 20%. Thus, based on the formula [7'] in section 2.4, the estimated severity index is 0.20 and 0 for first and second outbreaks respectively.

In contrast, the adoption of the least comprehensive intervention strategy (strategy 16) only reduces the probability of the presence of the virus from 80% in the first outbreak to 60% in the subsequent outbreak with the no improvements on biosecurity. In addition, the proportion of sow susceptible decreases from 80% in the first outbreak to 60% in the second outbreak due to the implementation of back-load gilt introduction along with the average feedback practices. Consequently, the severity index is 0.64 and 0.36 for the first and second outbreaks respectively. Depending on the gilt introduction strategies, the estimated values of severity index for the other 15 strategies are assumed to vary between the values for the most and least comprehensive strategies.
4.5 Economic Analysis

The economic simulations include an economic base scenario and a PED outbreak scenario. Under the baseline scenario, weekly pig numbers by population cohorts and weekly net revenues for the pre-event 52-week farm production are simulated. Under the PED outbreak scenario, the impact of PED outbreak, which includes two outbreaks, was simulated. The calculation of economic losses due to PED on farm production is described in equation [2]. In addition, economic losses of PED are decomposed to losses due to the first outbreak and the second outbreak separately. Specifically, in order to estimate the losses due to the second outbreak solely, which is the difference in losses between the PED base outbreak and a PED incident with only the first outbreak, the impact of a PED outbreak with only the first outbreak is simulated. The loss reduction result from the use of each intervention strategy is calculated by approaches described in section 4.4.

4.6 Summary to Chapter

This chapter provides the detailed description of the empirical model that designed to estimate weekly pig numbers by population cohorts and weekly net returns generated by the farm owner. Production parameters, production costs and returns for both normal production and the PED base outbreak scenarios, which obtained from literature and government reports, are used in the model in order to estimate the base PED outbreak losses. The concept of severity index is developed to define the net benefit of each intervention strategy in reducing PED outbreak losses. In addition, based on the discussion of the effectiveness of each control and eradication measures, the overall effects of intervention strategies on PED control and elimination is estimated. The next chapter will describe the simulation results from the empirical model.
CHAPTER 5

SIMULATION RESULTS

5 Introduction to Chapter

This chapter provides the overview of the simulation results. The base results for the production under no disease scenario are given and validated by comparing with real data. The estimated results for the losses at the hog, sow and whole farm level are given, followed by a sensitivity analysis in order to evaluate the effects of various parameters.

5.1 Base Scenario without PED (π)

Under the base scenario, 327 piglets are weaned steadily per week from a herd of 700 sows (Figure 5.1 & Figure 5.2), given the parameters for sow farrowing rate (85%), piglets born alive per sow per litter (11 and 12 for gilts and sows respectively) and the pre-weaning mortality rate (13%), the farm sells 296 hogs for each week (Figure 5.2). Weekly net income from hog sales is $6,251 per week (Figure 5.3). The annual net returns to labor, management and equity are approximately $20.96 per market hog (Table 5.1). The return per market hog for a farrow-to-finishing farm in Ontario has varied from -$17.94 to $60.07 between 2011 and 2014 (OMAFRA, 2011-2014). Given the relatively high market prices assumed in the simulation, the results suggest the base model estimates are typical for Ontario farrow-to-finish producers.

5.2 PED Base Outbreak Scenario (π_D)

Under the base PED scenario, the weekly number of sows in inventory declines from 700 to around 600 over the 16-week breeding herd closure while it increases gradually towards pre-event level after herd reopened (Figure 5.1). There is a significant increase in the number of
piglets weaned in week 1 (1,005 heads) because of the implementation of early weaning, which involves moving all piglets from the farrowing room (Figure 5.1). No piglets enter the nursery for the next 10 weeks due to 7 weeks with a 100% pre-weaning mortality rate and 3 weeks of a suckling period. The weekly number of piglets weaned starts to rebound in week 12 as pre-weaning mortality losses decline and production partially recovers by week 14. However, the average number of piglets produced weekly in the post PED period falls compared to the base scenario without PED (308 vs 327) as the overall number of sows decreases due to herd closure.

Changes in weekly piglet production from PED are reflected in the subsequent number of nursery and finishing pigs (see Figure 5.3 and Figure 5.4 respectively). The 502 early weaned piglets moved to the nursery at the outbreak of PED pushes up the ending inventories for feeder pigs in week 9 to 485 and for finishers in week 25 to 387. The 10-week period of no production from the sow herd is reflected in ending inventories in the nursery from week 10 to week 19 and in the finishing barn from week 26 to week 35. The ending number of feeder pigs and finishers starts to recover from week 20 and week 36 respectively.

The second outbreak of PED starts in week 18 with 4 consecutive weeks of 50% pre-weaning mortality losses. The number of piglets weaned weekly decreases from 308 to 32 between weeks 18 and 24, rebounds in week 25, and stabilizes at around 300 after week 29. Consequently, the ending inventories of feeder pigs drops between weeks 27 and 32 and of finishers between weeks 42 and 50. Market hog numbers recover in week 51 after the second outbreak of PED in week 18.

The estimated monetary losses due to PED are illustrated in Figure 5.4. Although the physical impacts of PED virus begin in week 1, the financial impacts are not felt until week 26 when revenues fall dramatically as there are no hogs to market. Net income actually increases
after the PED outbreak until week 25 as production costs decrease with the reduction in pigs to
feed. However, from week 26 to week 36, the PED-affected farm suffers a total loss of $321,412.
The net income begins to rebound in week 38 but the second outbreak imposes another loss of
$209,884 from weeks 44 to 52.
Figure 5.1 Weekly Number of Sows in Inventory (Base & PED); PED outbreak occurring in week 1
Figure 5.2 Weekly Flows of Weaned Piglets into the Nursery House (Base & PED); PED outbreak occurring in week 1
Weekly Flows of Feeder Pigs to the Grow-finishing House

Figure 5.3 Weekly Flows of Feeder Pigs into the Grow-finishing House (Base & PED); PED outbreak occurring in week 1
Figure 5.4 Weekly Ending Inventory of Finishers (Base & PED); PED outbreak occurring in week 1
Figure 5.5 Weekly Net Revenues (Net Losses) (Base & PED); PED outbreak occurring in week 1
Table 5.1 compares differences in the total number of market hogs, the weekly number of sows in inventory, annual revenues and costs between base scenario and PED scenario at the hog, sow and whole farm levels. When compared to the base scenario, on a hog basis, PED leads to a $20.51 decrease in net returns. On a sow place, $809.37 is saved on the overall costs while forgone revenues are $1,261.44. Thus, a net loss of $452.07 per sow is due to PED. A total loss of 5,138 marketed hogs attributed to PED results in $976,890 of foregone net revenues, despite the total saved costs is $658,834.76. As a result, the net farm income is $318,055.98 worse off in case of a PED outbreak.
Table 5.1 Net Revenues (CND) and Market Number of Hogs (Heads) from Base and PED Outbreak Scenarios

<table>
<thead>
<tr>
<th></th>
<th>Farm Level</th>
<th>Hog Level</th>
<th>Sow Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Revenues</td>
<td>2,936,959.30</td>
<td>1,960,068.56</td>
<td>976,890.74</td>
</tr>
<tr>
<td>Feed Costs</td>
<td>1,975,843.81</td>
<td>1,429,663.82</td>
<td>546,179.99</td>
</tr>
<tr>
<td>Net Culling Costs</td>
<td>56,272.37</td>
<td>54,786.30</td>
<td>1,486.07</td>
</tr>
<tr>
<td>Others</td>
<td>582,130.38</td>
<td>470,961.69</td>
<td>111,168.69</td>
</tr>
<tr>
<td>Total Costs</td>
<td>2,614,246.57</td>
<td>1,955,411.81</td>
<td>658,834.76</td>
</tr>
<tr>
<td>Net Revenues</td>
<td>322,712.74</td>
<td>4,656.75</td>
<td>318,055.98</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total Number of Marketed Hogs</th>
<th>Base</th>
<th>PED</th>
<th>Diff.</th>
<th>Base</th>
<th>PED</th>
<th>Diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15,394</td>
<td>10,256</td>
<td>5,138</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Average Number of Sows in Inventory</th>
<th>Base</th>
<th>PED</th>
<th>Diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>703</td>
<td>672</td>
<td>31</td>
</tr>
</tbody>
</table>
5.3 PED Intervention Scenarios

The estimated monetary benefits from each intervention strategy are listed in Table 5.2. The intervention strategy with the highest financial returns is strategy 6, which involves front-load gilt introduction, average feedback and intensification of biosecurity security protocols. This strategy costs $14,000 but reduces the losses from PED from $318,005 to $55,005 for a benefit of $277,000 and an overall net return of $263,000. However, three other strategies (1, 3, and 5) generate more than $250,000 in net benefits and there are 13 strategies with more than $200,000 in the overall loss reduction. Even the least profitable strategy (16) results in large net benefits to its employment ($157,000).

While all strategies are profitable, the net returns depend on the combination of practices employed. The most intensive, and also expensive, set of practices (strategy 1) is not the most profitable and neither are the options that are least expensive (strategies 8 and 16). The latter strategies involve minimal cost and have the second highest benefit to cost ratio, but the absolute levels are lower than any of the other options.

The most profitable strategies tend to involve intense biosecurity protocols; six of the eight with the highest net returns have high levels of biosecurity in place (strategies 1, 2, 3, 5, 6, 9, and 13). The enhanced biosecurity efforts cost an extra $13,000 but generate reductions in losses greater than this cost with the extent of the reduction depending on the combination of other strategies employed. For example, the extra biosecurity reduces losses by an extra $15,000 (=$284,000-$269,000) when the high level of effort is used with the other 3 practices (strategy 1 vs. strategy 3) while it increases to $24,000 (=$261,000-$237,000) when front-loading and good feedback but no vaccination (strategy 2 vs. strategy 4).
Front-loading of gilts is another profitable practice. The costs of front-loading are essentially the same as back loading but the benefits are greater due to the enhanced immunity levels. The value of front-loading is partially through the elimination of the second outbreak of PED and its subsequent costs of $155,768. Vaccination can also reduce the impact of a second outbreak by decreasing the proportion of susceptible sows. The cost-effectiveness of front-loading versus vaccination depends on the combination of other practices. For example, strategy 6 and strategy 13 both use an average feedback effort and intensive biosecurity protocols but differ in terms of choice of loading and vaccination. Strategy 6 uses front-loading while strategy 13 uses vaccination to increase the share of sows immune to PED and the net returns are approximately $19,000 higher. In contrast, vaccination is a more cost-effective approach to enhance immunity if intensive levels of effort are used in both feedback and biosecurity implementation. The net return to using vaccination and these two practices (strategy 9) is approximately the same if no vaccination is used and gilts are front-loaded (strategy 2). Vaccination is generally profitable unless an average level of feedback and intensive biosecurity protocols are used (strategies 5 vs. 6, and strategies 13 vs. 14).

The strategy with the use of good feedback practice is more profitable than that with the average option, when other practices employed are the same. However, exceptions are for strategy 2 and strategy 6 as well as strategy 10 and strategy 14. Specifically, net benefits from strategies include the good feedback practice with front loading or back loading and intensive biosecurity efforts are less than those generated from strategies with the average feedback practice.
Table 5.2 Net Losses (CND 1,000) from First and Second PED Base Outbreak, and Net Benefits (CND 1,000) from Each Intervention Strategies

<table>
<thead>
<tr>
<th>Intervention Strategies</th>
<th>PED Base Outbreak</th>
<th>Net Losses</th>
<th>Losses Reduction</th>
<th>Intervention Expenditures</th>
<th>Net Benefits</th>
<th>Benefit-cost Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>First Outbreak</td>
<td>Second Outbreak</td>
<td>Total</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gilt Intro. Feedback Bios. Vacc.</td>
<td>First Outbreak</td>
<td>Second Outbreak</td>
<td>Total</td>
<td>Intensive No Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Front Average Intense No</td>
<td>122 156 277</td>
<td>14</td>
<td>263 19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Front Good Intense Yes</td>
<td>128 156 284</td>
<td>27</td>
<td>257 10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Front Good Average Yes</td>
<td>114 156 269</td>
<td>13</td>
<td>256 19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Front Average Intense Yes</td>
<td>122 156 277</td>
<td>25</td>
<td>252 10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 Back Good Intense Yes</td>
<td>117 156 273</td>
<td>27</td>
<td>246 9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Front Good Intense No</td>
<td>105 156 261</td>
<td>16</td>
<td>246 16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13 Back Average Intense Yes</td>
<td>114 156 269</td>
<td>25</td>
<td>244 10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 Front Average Average Yes</td>
<td>97 156 253</td>
<td>12</td>
<td>241 20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 Back Good Average Yes</td>
<td>97 156 253</td>
<td>13</td>
<td>240 18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14 Back Average Intense No</td>
<td>97 156 253</td>
<td>14</td>
<td>239 17</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Front Good Average No</td>
<td>81 156 237</td>
<td>2</td>
<td>235 102</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 Back Good Intense No</td>
<td>94 143 237</td>
<td>16</td>
<td>222 14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 Back Average Average Yes</td>
<td>84 137 221</td>
<td>12</td>
<td>210 18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 Front Average Average No</td>
<td>71 118 190</td>
<td>1</td>
<td>189 246</td>
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<tr>
<td>12 Back Good Average No</td>
<td>65 125 190</td>
<td>2</td>
<td>187 81</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16 Back Average Average No</td>
<td>58 100 158</td>
<td>1</td>
<td>157 205</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5.4 Sensitivity Analysis

Sensitivity analysis was conducted to demonstrate the effects of changing cost and effectiveness parameters of the control measures. As suggested by the large positive net returns for each of the 16 strategies, the significant increases in cost and/or reductions in the effectiveness of the practices do not change the positive net returns to employing the control strategies. The effects of increasing cost by 100% and reducing the effectiveness parameters by 100% on the loss reduction from the PED base scenario are listed Tab.6.

Increasing the costs for disinfection materials and utilities do not alter the ranking of intervention strategies, while increases in wages lead strategy 3 to be the most profitable strategy. Specifically, increases in wages result in decreasing net benefits of strategy 3 by 1% to $252,000 while reducing net benefits of strategy 6 by 5% to $250,000.

In contrast, a 100% decrease in the effectiveness of biosecurity effort on reducing the likelihood of virus being present in the herd does alter the ranking of the most profitable strategy. The decrease in the effectiveness of the biosecurity effort results in an 15% reduction of net benefits from strategy 6 to $223,000 whereas strategy 3 becomes the most profitable strategy with merely decreases in net benefits. Similarly, a 100% increase in the probability of virus being present in the herd, which caused by the use of feedback practice, also changes the ranking of the most economic efficient strategies. The increases in contamination by using feedback practice decrease net benefits from strategy 6 by 3% to $255,000, while does not change net benefits from strategy 3. Therefore, strategy 3 overpasses strategy 6 and becomes the most cost-effective intervention strategy. Changes in other effectiveness parameters do not alter the ranking of the most economic efficient intervention strategy.
Table 5.3 Results from Sensitivity Analysis on Costs and Effectiveness Parameters for Intervention Strategies

<table>
<thead>
<tr>
<th>Cost Parameters</th>
<th>100% Decreases</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
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<tr>
<td>Labor</td>
<td>32</td>
<td>241</td>
<td>231</td>
<td>252</td>
<td>232</td>
<td>238</td>
<td>250</td>
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<td>157</td>
</tr>
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<td>Disinfectants</td>
<td>1,476</td>
<td>-6%</td>
<td>-6%</td>
<td>-1%</td>
<td>-1%</td>
<td>-6%</td>
<td>-5%</td>
<td>-1%</td>
<td>0%</td>
<td>-7%</td>
<td>-7%</td>
<td>-2%</td>
<td>-1%</td>
<td>-6%</td>
<td>-5%</td>
<td>-1%</td>
<td>0%</td>
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<tr>
<td>Utilities</td>
<td>600</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
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<td>0%</td>
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<td>0%</td>
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<tr>
<td>Vaccination</td>
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<td>0%</td>
<td>-4%</td>
<td>0%</td>
<td>-4%</td>
<td>0%</td>
<td>-4%</td>
<td>0%</td>
<td>-4%</td>
<td>0%</td>
<td>-4%</td>
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<td>-4%</td>
<td>0%</td>
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<td>0%</td>
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<tr>
<td>Gilt Intr.</td>
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<td>-9%</td>
<td>-19%</td>
<td>-13%</td>
<td>-40%</td>
<td>-6%</td>
<td>-6%</td>
<td>-26%</td>
<td>-34%</td>
<td>-5%</td>
<td>-11%</td>
<td>-7%</td>
<td>-25%</td>
<td>-3%</td>
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<td>-20%</td>
</tr>
<tr>
<td>Feedback PS</td>
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<td>174</td>
<td>176</td>
<td>92</td>
<td>244</td>
<td>255</td>
<td>210</td>
<td>157</td>
<td>187</td>
<td>150</td>
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<td>45</td>
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<td>126</td>
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<tr>
<td>Feedback PV</td>
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<td>-18%</td>
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<td>-61%</td>
<td>-3%</td>
<td>-3%</td>
<td>-13%</td>
<td>-17%</td>
<td>-24%</td>
<td>-32%</td>
<td>-46%</td>
<td>-76%</td>
<td>-3%</td>
<td>-3%</td>
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<td>-20%</td>
</tr>
<tr>
<td>Vaccination</td>
<td>0</td>
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<td>0%</td>
<td>-13%</td>
<td>0%</td>
<td>-6%</td>
<td>-6%</td>
<td>-26%</td>
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<tr>
<td>Feedback PV</td>
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<td>0%</td>
<td>0%</td>
<td>-3%</td>
<td>-3%</td>
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<td>-13%</td>
<td>-8%</td>
<td>-22%</td>
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<td>0%</td>
<td>-7%</td>
<td>-6%</td>
<td>-8%</td>
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<tr>
<td>Bios.</td>
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<td>-6%</td>
<td>-10%</td>
<td>0%</td>
<td>0%</td>
<td>-16%</td>
<td>-15%</td>
<td>-7%</td>
<td>-25%</td>
<td>-8%</td>
<td>-22%</td>
<td>0%</td>
<td>0%</td>
<td>-33%</td>
<td>-31%</td>
<td>-15%</td>
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</tbody>
</table>
CHAPTER 6

DISCUSSION AND CONCLUSION

6 Introduction to Chapter

Chapter 6 discusses the significant research outcomes, the contributions and implications for PED control and elimination management in Ontario swine farms. In the end, limitations faced by this study and recommendation for future research are outlined.

6.1 Discussion to Results

This study investigates the cost-effectiveness of PED control and eradication strategies for a farrow-to-finishing commercial system. The paper presents a simulation model based on Microsoft Excel© Spreadsheet for the farrow-to-finish operation to estimate weekly pig flows by population cohorts and weekly farm net returns. We also developed a simple conceptual framework to determine the most economic-effective combination of control and elimination practices for PED. The economic losses associated with each of 16 intervention strategies are assessed on the basis of the PED severity index as well as its implementation expenditures. The most profitable strategy achieves the largest amount of loss reduction from PED base outbreak, which is the difference between the overall benefits from loss reduction and the associated intervention expenditures.

The results emphasize the importance of implementing intervention strategies in controlling the PED outbreak, and preventing the repeated outbreaks. Any of 16 PED intervention strategies discussed in this paper can reduce the economic losses of a PED outbreak in the farrow-to-finishing farm. Specifically, the most economic profitable PED intervention strategy includes the use of front-load gilt introduction in timely herd closure along with the average
feedback effort in combination with intensive efforts on biosecurity protocols. However, net returns to individual intervention practices depends on other practices employed. The timely herd closure has been reported as the least cost intervention measure in eliminating PRRSv (Yeske, 2010). The paper also found the evidence that the immediately herd closure along with feedback practice contribute to significant loss reduction in case of a PED outbreak. For instance, even the implementation of the least comprehensive strategy (strategy 16), which involves the back-load gilt introduction and the average feedback practice, leads to save around $160,000 economic losses caused by a PED outbreak. In addition, the study also found that strategies with the adoption of front-load gilt introduction in managing gilt pool contributes to more loss reduction from a PED base outbreak than those with the end purchase of gilts. This can be explained by Batista et al. (2002) since the front-loaded gilts will be exposed to feedback materials with the old animals simultaneously, which results in the establishment of complete herd immunity. However, farmers should be cautious in choosing feedback practice as it can lead to environmental contamination by spreading feedback materials in the herd. Therefore, the implementation of biosecurity improvements becomes crucial in controlling a PED outbreak as it reducing the probability of virus being present in the herd, which results in lowering the overall severity score. Despite the extra spending on biosecurity improvements, the overall loss reductions achieved by the intensive biosecurity effort can be significant (eg. $257,000 from strategy 6) and results in the high net benefit. The evidence of adopting biosecurity improvements in increasing the overall profitability of swine farm production can be also found in Meuwissen et al. (1999) in case of classical swine fever outbreaks in Netherland. Vaccination can be used as a supplement practice especially when the intensive efforts are invested on feedback and biosecurity protocols. The results do not suggest the use of vaccination as an option
in the most cost-effective set of intervention practice. This is because the massive use of vaccination leads to high implementation expenditures. Overall, the combination of herd closure and feedback together with biosecurity improvements is considered to be the most profitable intervention strategy in case of a PED outbreak.

6.2 Contributions of the Study

This study has made several empirical and methodological contributions. To our knowledge, this is the first study that estimated economic losses of PED and determined the most economic-effective strategy in Ontario. The empirical results show the tremendous losses caused by PED. The analysis on the cost-effectiveness of PED intervention strategies highlights the importance of adopting control and elimination practices.

The study develops a simulation model to estimate pig flows by population cohorts and net returns of farm production. The model was developed in a spreadsheet so that it can be easily adapted to suit other swine disease. Furthermore, in this study we used a severity index to define the extent and severity of different PED outbreaks. This concept has a broad implication in economics of animal health since it helps to quantify the impacts of disease on livestock production. However, it does require the further study to empirically define the extent and severity of disease outbreaks.

6.3 Limitation and Recommendation for Future Research

The study estimated the economic losses of a PED outbreak in a farrow-to-finishing farm are $452 on the sow basis, with only breeding closure is employed. The reports on economic costs of a PED outbreak can be also found in Provis (Elanco Animal Health, winter 2014), in which the
economic losses of PED on the sow place are $432 under the poor management scenario and $243.00 under the good management scenario. Results from this study seem consistent with Provis’ estimation. However, more research on PED economic costs is required in order to conduct comparison.

The analysis simplified the impact of PED on digestibility for finishers by taking account of feed costs for two more weeks. As feed cost is the largest part of production costs in a farrow-to-finishing production, future study should use the fattening performance indicators, which include average daily gain (ADG), average daily feed intake (ADFI) and feed conversions ration (FCR) ((Alvarez et al., 2015), to further analysis the PED impact on the grow-finishing herd.

So far, swine specialists and farm owners have a good understanding of PED impact on farm production and several intervention practices have been adopted to control and eliminate disease outbreaks. However, the scientific research on the effectiveness of each intervention practice is scarce. Therefore, we have made several assumed values for the effectiveness parameters. Further studies on the effectiveness of each control and eradication measures are required.

Furthermore, though the spreadsheet model developed in this study can be easily adapted to suit other swine disease, future studies should include stochasticity elements that depict dynamic nature of infectious disease outbreak. In addition, further analysis is needed to evaluate the PED impact in the larger context (e.g. at regional and national level).
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