# The Economic and Production Impact of Porcine Reproductive and Respiratory Syndrome on Nursery and Grower-Finisher Pigs

**by**

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# ABSTRACT

## THE ECONOMIC AND PRODUCTION IMPACT OF PORCINE REPRODUCTIVE AND RESPIRATORY SYNDROME



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This thesis is an investigation of the changes in production performance in nursery and grower-finisher pigs associated with an outbreak of porcine reproductive and respiratory syndrome (PRRS) and an examination of the economic impact of this disease. The production records from herds experiencing a PRRS outbreak were used. The 6-month period prior to the outbreak was compared to the 6-month period after the outbreak and to the period 7-12 months after the outbreak. Cost was attributed based on the average reduction in performance parameters including growth rate, feed efficiency and mortality. The overall cost per annum to nursery and grower-finisher pigs due to PRRS in the Ontario was estimated to be approximately $4 million. This value was calculated by developing an economic model taking into account the size of the Ontario swine population and the average incidence of PRRS outbreaks.

# DEDICATION

In memory of my parents

In memory of Carl Clayton

To my friends and family

Thanks for all of your support.

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| | |
|---|---|
| AASV | American Association of Swine Veterinarians |
| ADG | Average daily gain |
| AIAO | All-in All-out |
| AIC | Akaike Information Criterion |
| CF | Continuous Flow |
| Coef. | Coefficients |
| df | Degrees of Freedom |
| ELISA | Enzyme Linked Immunosorbant Assay |
| FA | Fluorescent Antibody |
| FCR | Feed Conversation Ratio |
| IFA | Indirect Fluorescent Antibody |
| IgA | Immunoglobulin Type A |
| IgG | Immunoglobulin Type G |
| IgM | Immunoglobulin Type M |
| IHC | Immunohistochemistry |
| IPMA | Immunoperoxidase Monolayer Assay |
| Iqr | Interquartile Range |
| IR | Incidence Rate |
| MLV | Modified live viruses |
| NAHMS | National Animal Health Monitoring System |
| OSHAB | Ontario Swine Health Advisory Board |
| PCR | Polymerase Chain Reaction |
| PRRS | Porcine Reproductive and Respiratory Syndrome |
| RR | Risk Ratio |

| | |
|---|---|
| SD | Standard Deviation |
| VN | Serum Virus Neutralization |
| Wald Chi Sq | Wald Chi Square |

# CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

## 1.1 Introduction

Porcine reproductive and respiratory syndrome (PRRS) is the most important disease of swine in Canada. The disease was first recognized in the late 1980s with the causative agent porcine reproductive and respiratory syndrome virus (PRRSv) isolated in the early 1990s (1). Despite the creation of vaccines (2), the development of accurate diagnostic tests (3) and the development of control protocols (4), PRRS remains a major problem causing economic losses in a large number of Canadian swine herds.

Porcine reproductive and respiratory syndrome is a highly variable clinical syndrome with two major components. Firstly, reproductive failure manifested through outbreaks of late gestation abortions, increased numbers of stillbirths and mummified fetuses, weak neonates, high pre-weaning mortality, and a high rate of return to estrus (5). The other component is respiratory disease characterized by anorexia, fever, dyspnea, polypnea, coughing, and impaired growth rates affecting mostly suckling and weanling pigs (6).

The economic impact of PRRS outbreaks and the cost-benefit of various intervention strategies are not well documented. Most attention has been directed at losses observed in breeding herds and nursing piglets; however, in endemic PRRS infections the disease is mostly expressed as a respiratory infection of nursery pigs and grower hogs resulting in reduced growth rates.

## 1.2 Etiology

Porcine reproductive and respiratory syndrome (PRRS) is caused by a small positive-strand RNA virus morphologically and genomically similar to members of the family *Arteriviridae*. The virus was first isolated in Lelystad, Netherlands in 1991, and originally was called the Lelystad virus (7); however, it was later renamed as porcine reproductive and respiratory virus (PRRSv) type 1. It is closely related to the equine arteritis virus. The PRRS virus is highly host restricted with a primary site of virus replication being porcine alveolar macrophages (8). This virus is enveloped and ranges in size from 45-80 µm. Inactivation is possible after treatment with chloroform or ether. It is very stable under freezing conditions retaining the possibility of infection up to 4 months at -70° C. Infectivity is greatly reduced as temperature rises (15- 20 minutes at 50° C). It may survive for several years in deep frozen tissues, but only one month at 4° C, and 48 h at 37° C (9). Strains of PRRSv have a host of identical properties but can vary in their antigenic differences, their exceptional genomic diversity, in diverse clinical presentation of the disease, as well as differentiated reactivity with polyclonal and monoclonal antibodies and differences in RNA sequences (10). Genetic sequencing has become routine practice in diagnostic assessment of a PRRS outbreak. Strains of the virus from Canada and United States have been shown to be relatively similar antigenically but different from the European Lelystad virus isolate (11). The North American virus has been designated PRRSv Type 2. The effects of the virus on reproductive performance are strain dependent (2). Some strains cause severe lesions of the lymphoid and respiratory system which are major sites of viral replication. The difference in pathogenicity may explain the variation in severity of clinical disease observed in field outbreaks (12).

### 1.3 Epidemiology

Transmission of the virus is known to be carried out through direct and indirect means. By far the most important way of transmission is pig to pig. The virus spreads relatively fast within an infected farm, and this spread is generally considered to be accomplished through direct contact (13). The virus is present in saliva, semen, nasal discharge, urine and feces. Therefore, virus can be transmitted through bites, intramuscular injections, and oral-nasal contact. Infected pigs may remain carriers for up to 15 weeks (14).

Continuous flow of pigs into and out of nurseries may lead to persistent herd infection because disease is constantly passed from older infected animals to naive newly-introduced animals (15). Co-mingling pigs from various sources of unknown immune status in nurseries or grower-finisher barns can lead to persistent virus circulation. Contaminated semen plays an important role in virus introduction into a negative herd (16). Vertical transmission is also an important method of maintaining the infective status of a herd. Transplacental passage of the virus to fetuses leads to embryonic or fetal death or the birth of viremic piglets (17).

Indirect transmission of PRRS virus involves vectors, fomites, and maybe airborne spread (18). Stability of the virus in the environment is generally of short duration because the virus is inactivated by heat and drying. However, in cold and damp environments the virus is quite resistant and stable for months or years at -20°C and -70°C (19). Changing coveralls, boots and washing hands are sufficient protocols to stop transmission via human visitors (20). Transportation with inadequate biosecurity measures (unwashed trucks) plays an important role in viral transmission from farm to farm (21). Airborne transmission is difficult to document. Experimental airborne transmission over short distances up to 2.5 m has been described (22). In contrast, other studies reported presence of some strains of infectious PRRS virus in the air for up to 9 km from an infected herd (23). Further investigation of this infectious pathway still needs to be conducted. Arthropods are considered vectors in PRRSv transmission, but only mechanical transmission has been demonstrated (24, 25). Air filtration has been shown to be effective in prevention of airborne transmission. Initially, high cost and maintenance has limited use of filtration to nucleus herds and AI studs (26), although air-filtration has recently become more accepted in parts of US swine industry with high pig density.

### 1.4. Clinical Signs

Reproductive failure and respiratory disease are the two major components of the clinical manifestation of PRRSv infection. Within a herd, pigs in all stages of production could be infected concomitantly or sequentially. Clinical presentation varies greatly from herd to herd renging from infection with no apparent clinical signs to outbreaks involving high mortality rates. The characteristics of severity depend on virus strain and herd immune status, as well as the presence of co-infections and management factors (6). The reproductive aspect of the disease may be preceded by respiratory disease. Anorexia, lethargy, depression and mild fever in pregnant gilts and sows are clinical findings in 5 to 50% of the animals. In the following days a surge in early farrowings, late-term abortions, increased number of stillbirths and mummified fetuses, low viability neonates and high pre-weaning mortality are characteristic of a severe PRRS outbreak in the breeding herd. Breeding performance is also affected with an increase in wean-to-estrus intervals and repeat matings. The reproductive aspect of the disease usually lasts from 4 to 5 months followed by a return to normal performance. Recurrent incidents are described when replacements gilts are introduced with insufficient time to mount protective immunity (27). A large number of herds return to a near normal reproductive performance with clusters of reproductive failure reported from time to time, while other herds never quite achieve pre-infection performance levels (28).

The characteristic presentation of clinical signs in young pigs in the nursery is as follows: anorexia followed by fever, respiratory distress, coughing, and altered growth rates. In some herds morbidity runs as high as 30% with a mortality of 10%. These numbers can vary, and are influenced by co-infections with *Streptococcus suis, Hemophilus parasuis, Actinobacillus suis,* etc. (6). Studies have shown that PRRSv interacts synergistically with *Mycoplasma hyopneumoniae* in producing a more serious respiratory disease (29), and most likely a similar relationship exists between PRRSv and other swine respiratory pathogens.

**1.5. Diagnosis**

Since first described as a disease entity, diagnostic methods have been developed and refined. Diagnostic investigation to establish PRRSv infection status of a herd is usually warranted when breeding herd records show poor reproductive performance with a sudden drop in conception rates, increased repeat services, increased pre-weaning mortality, and increased numbers of stillbirths and mummies. Differential diagnostics need to consider infection from: porcine parvovirus, pseudorabies virus, swine influenza virus, porcine circovirus, enterovirus, cytomegalovirus, *Leptospira* sp, and encephalomyocarditis virus (30).

Gross pathology findings are uncharacteristic in aborted fetuses or stillborn piglets. In nursing and grower pigs, infection with PRRS virus is characterized by interstitial pneumonia and enlargement of the lymph nodes (30). Tissue samples from lung, lymph nodes, heart, brain, thymus, spleen, and kidneys may be formalin fixed and submitted for microscopic evaluation and immunohistochemistry (IHC). This method allows visualization of cells containing PRRSv antigens in the cytoplasm (31).

Positive diagnosis is based on obtaining evidence of PRRSv infection in animals suspected of harbouring the infection. To achieve this goal, isolation of PRRSv or detecting PRRS viral antigens or nucleic acid in the animals is required. Virus isolation is performed by using cell cultures of porcine alveolar macrophages (PAMs) and certain African monkey kidney cell lines (32). Sample selection for virus isolation should consist of serum, lung, and bronchial alveolar lavage fluid in acute infected animals. Tonsil, orophargyneal scraping, and bronchial alveolar lavage fluid are better samples than serum and lung when attempting to isolate virus from persistently infected animals (33).

Fluorescent antibody (FA) test and IHC test may be used for detecting PRRSv antigen in tissues. The FA technique is an inexpensive and rapid test used to detect viral antigen in frozen lung and spleen tissue. The test is highly specific but not very sensitive, and test results are affected by tissue autolysis. The IHC test is more sensitive than direct FA but is more expensive and time consuming (31). Preferred tissues for this test are heart, kidney, lung, lymph nodes, spleen, thymus, and tonsil. Antigens may also be detected in intestine, liver, and occasionally in brain (30). Polymerase chain reaction (PCR)-based tests have been developed for detecting PRRSv genomic material (RNA**)** in clinical specimens. This method is fast since it does not require virus isolation in cell culture. In general, PCR assays are considered to be highly sensitive and highly specific (34). At least one study challenges this assumption arguing that this might not always be the case (35). Some PCR assays use a “nested” procedure (RT-nPCR) for added sensitivity (33). Automated fluorogenic PCR-based tests such as TaqMan™ PCR (36) or Molecular Beacon are methods frequently used by laboratories. They are also known as “real time” PCR. For detection of viral RNA in boar semen RT- PCR is the technique most commonly used (33). Polymerase chain reaction assays have become common, both for the diagnosis of PRRS and to aid in herd monitoring, i.e. screening of replacement gilts and boars, as well as for test and removal programs. It is important to keep in mind that a positive result on PCR indicates the presence of viral RNA and does not necessarily indicate the presence of live PRRSv (33). Serology is the most common diagnostic method used by field veterinarians because serum is easily collected and stored for future references. There are five serological tests used to detect antibodies to PRRS virus: indirect fluorescent antibody (IFA), enzyme linked immunosorbant assay (ELISA), blocking ELISA, serum virus neutralization (VN) and immunoperoxidase monolayer assay (IPMA). The IFA test is considered to have high specificity (99.5%) but unknown sensitivity for individual animals. The IFA test is a reliable test to detect specific antibodies for 2-3 months after infection. An IFA test for the detection of PRRS virus-specific IgM antibodies has been developed (38). A titer of 16 or 20 is considered positive. Commercially available ELISA tests are considered to be highly sensitive and specific (14). The specificity of HerdCheck® PRRS ELISA has been estimated to be between 99.3 and 99.5% (39). The advantage of the commercial ELISA includes detection of antibodies against both North American and European PRRS virus strains.

Commercial PRRS ELISA tests have been adapted to test oral fluid samples. PRRSv IgM, IgA, and IgG may be detected using a low cost effective method to monitor the presence of maternal antibodies in commercial herds or measure previous exposure to virus (40). Most recently this method was validated in Ontario to be used in regional PRRSv control and elimination programs.

### 1.6. Control

Once the diagnosis of a PRRS infection has been determined, appropriate strategies to control the virus spread and reduce the clinical effect of the disease can be enacted. The long-term objective of controlling PRRS on a farm is to stop the spread from carriers to susceptible animals. Animal to animal spread in the breeding herd may be slow, but sows remain infectious for long periods of time. It is important to ensure that there aren't pockets of naïve sows within the positive breeding herd, and this includes incoming gilts. The continuous infection of new animals will perpetuate the infection. Various strategies to control PRRS have been developed, including complete depopulation and repopulation or herd closure and rollover (41), gilt development isolation/acclimatization (27), partial depopulation (42), all-in/all–out (AIAO) pig flow, and vaccination or planned exposure (43).

*1.6.1 Herd closure and rollover*

This method involves an interruption in the flow of replacement gilts for a period of time (usually 180-200 days) followed by the entry of only PRRSv-negative females and boars. Gradually the breeding animals previously exposed are eliminated from the herd. The negative status of replacement gilts depends on successfully applying protocols of isolation and acclimatization. The main disadvantage of this method is the economic loss due to the negative effect on parity distribution. For a period of time the herd retains older and less productive sows rather than culling these animals because replacements are not available.

*1.6.2 Gilt development isolation / acclimatization*

A gilt development facility is helpful for successfully preparing gilts for entry onto an infected farm. It may be located on the sow site, but location on an alternate site is preferable (44). Gilts may be introduced as grower pigs at 2-3 months of age. The purpose is to prepare animals for PRRS virus infection prior to entry into the breeding herd (27). There are three distinctive phases to this program: isolation period, acclimatization period and recovery period. The length of each of these periods is ideally 30 days.

The isolation period consists of serological testing at entry to determine status of incoming animals. The acclimatization period starts after 30 days post-entry. The purpose of acclimatization is to expose new animals to farm specific strains of virus. Exposure to known virus-infected pigs is implemented (27). Cull sows may be mixed with gilts at the rate of one to every other pen. The recovery period is implemented to reduce the risk of introducing actively infected gilts into the breeding herd. Sources of the field virus are removed and the gilt population is allowed to recover for a 30 day period prior to entry.

*1.6.3 Partial depopulation*

This technique is effective for controlling post-weaning PRRS or eliminating virus from the weaned pig population. The advantages of partial depopulation are minimal disruption in pig flow and low cost. On the negative side, success is based on absence of virus transmission in a breeding herd (27). Generally this technique is used when the PRRS outbreak is over in the breeding herd and negative piglets are arriving into the nursery where they are becoming infected. By emptying the nursery and doing a thorough cleaning prior to restocking with newly weaned pigs the re-infection cycle is interrupted.

*1.6.4 All-in /all-out pig flow*

All-in/all-out pig flow consists of dividing buildings into individual rooms and allowing for thorough cleaning and disinfection of facilities between groups of pigs. Recently AIAO has been more strictly defined to refer to separate buildings and separate sites. All-in/all-out by room is now generally considered continuous flow because the chance of contamination between rooms is still high. The same applies to different sites of nursery and finishing facilities. This technique is very effective in reducing the horizontal spread of pathogens from older infected animals to those recently placed. A major advantage of AIAO pig flow is that it reduces the impact of concurrent bacterial infections as well as limits the spread of PRRSv from one stage of production to the next.

*1.6.5 Vaccination*

The purpose of vaccination is to obtain an immune response that will protect against clinical disease. Existing PRRS vaccines do not stop infection and are therefore labelled as “an aid in the reduction” of clinical disease. Modified live viruses (MLV) have proven to be more effective than killed vaccines (45). The main limitation attributed to PRRS vaccines is the limited cross-protection that might exist among PRRS virus strains. Planned exposure based on inoculating sows with serum collected from acutely affected pigs is commonly used in acute outbreak situations. The goal is to infect all of the sows at one time with the hope that this will create a homogeneously immune population (ie. stable population). This method has certain risks because the type of virus and the level of challenge are not easily controlled (6). The economic cost of creating the disease in the whole herd at the same time is rationalized by the idea that the duration of the infection in the entire population will be shortened. Analysis of the production losses from time of exposure to the time of PRRS stability status has been done by modeling two exposure programs and compacting the data (32) . Clearly these strategies are not mutually exclusive, in that planned exposure needs to be implemented with consideration of gilt introductions and after it is completed, nursery depopulation is likely a necessary step as well.

**1.7. Elimination of PRRSv**

The major road block in PRRS eradication is the ability of the virus to establish persistent infection in pigs (6). Studies have proved under experimental conditions that finisher pigs become infected after being commingled with sows that were experimentally infected with PRRSv 99 days earlier (33). Bierk et al. (46) described the ability of sows to harbour persistent PRRSv in tissues for up to 86 days post infection, and successfully transmit the virus to naïve control sows for up to 56 days post-inoculation. Isolation of virus from tonsils of infected pigs for as long as 157 days after inoculation was described by Wills et al. (13). Infection of pregnant sows at 85-90 days of gestation resulted in viremic piglets at birth that were able to transmit to controls for 7-16 weeks post-parturition (5). Persistence of the virus has been described in boars shedding virus in semen for 92 days post-inoculation (33). Eradication strategies that have been described include; whole herd depopulation and repopulation, test and removal, herd closure and partial depopulation.

### *1.7.1 Whole herd depopulation and repopulation*

This technique has been used successfully over the years to eliminate a wide range of pathogens, and as a method to enhance genetic improvement. The possibility of eliminating PRRS using this strategy depends on the status of the incoming replacement stock. Testing the incoming PRRS-free replacement animals during the start-up phase, in a separate building other than the breeding and gestation barn is critical. If negative, admittance of the population is granted. If positive, animals should be slaughtered to protect the herd's negative status. The main disadvantage of the procedure is that it is very expensive, and a long disruption in cash flow.

### *1.7.2 Test and removal*

This protocol has been successfully used to eliminate Aujeszky's disease virus and *Actinobacillus pleuropneumoniae*. The strategy consists of testing all breeding stock, identifying carriers, and removing them from the herd to prevent vertical transmission of the PRRSv. A combination of serological testing using ELISA and PCR for detection of viral protein is used to identify previously exposed, potentially-infected animals (37). Test and removal is highly effective but expensive, and it is not possible to distinguish PRRSv-vaccinated animals from infected animals.

### *1.7.3 Herd closure*

This method is extensively used by veterinarians in an attempt to "roll-over" sow herds. In the first stage, all existing breeding stock was exposed to PRRSv and when they have recovered they are immune to PRRS. In a second stage, all replacement animals are banned from introduction for 180-200 days or longer. Some herds remain permanently closed to live incoming animals from other sites.

The gilt pool undergoes acclimatization, which consist of exposure to field virus in a quarantine facility off-site. Reintroduction is conditional pending on achievement of negative status. In order to hit the breeding target, gilts could be bred and introduced at farrowing or late gestation upon testing. The success of this method depends on the negative status of the replacement animals as well as the certitude that there is no virus circulation in the sow population.

An important factor in achieving a stable negative status is the use a negative semen source. Use of seronegative animals as sentinels comingled with seropositive sows to ensure that there is no virus shedding taking place, is a good practice to implement.

### *1.7.4 Partial depopulation*

This method is used in endemically infected nursery pig population. Continuous flow nurseries are emptied, rigorously cleaned and disinfected before negative pigs are placed. Until this is possible pigs are shipped to alternative sites.

## **1.8. Economic Impact of PRRSv Infection in Swine Operations**

Most authors agree upon several economic parameters where financial losses are measurable: decreased farrowing rates, increased mortality, attrition, and increased respiratory disease.  Studies have been conducted to establish economic losses in acute PRRS outbreaks and in endemic infected herds. Polson (47) published a study regarding the economic impact of PRRS in farrow-to-finish herds. The reduction of profits due to a PRRS outbreak was US $236 / female, which represented an 80% reduction in expected profits in the year of the outbreak. The same study estimated the cost of PRRS infection in the grower-finisher population to average $6.25-15.25 per pig (combined nursery and finishing stage).

The economic impact on the grower-finisher segment of production has been rarely investigated. One study (48) that did examine the economic loss associated with infected nursery herds estimated that PRRS resulted in an increased mortality (from 1.9 % to 10.2 %), reduced average daily gain (from 0.38 to 0.26 kg/d), increased treatment cost per pig (from $0.73 to $18.21) and reduced feed efficiency (feed to gain ratio from 1.77 to 1.91).

The largest and most often cited study of the economic impact of PRRS reported a total annual impact of disease was estimated to be 66.75 million US dollars in breeding herds and 493.57 million US dollars in grower-finisher pigs which brings the total cost of disease to 560.32 million US dollars (49). This study used data from 10 grower-finisher farms and just 2 nurseries to estimate the cost of a PRRS outbreak in post-weaned pigs, but attributed about 80% of losses to these production stages. Data were aggregated to generate a value for the national herd. The analysis required an estimate of the percentage of the US swine herds that were impacted by PRRS. The National Animal Health Monitoring System (NAHMS) swine survey provided data to estimate PRRS in breeding herds, nursery, and grower-finisher pigs. The duration and impact of PRRS outbreaks were highly variable among farms. Some of the farms had clear outbreak periods that subsided in response to control measures imposed while on other farms PRRS persisted endemically in a chronic herd problem and high loses. The study assumed that the value for a weaned pig was $30.00 and concluded that there was a reduction in revenue of $45.00 / litter because of the decrease in numbers of pigs weaned per litter. A 10% decrease in farrowing rate compared with the rate of uninfected pigs was also one of the findings. Because of this, fixed costs increased by $13.75/litter and variable costs increased by $15.41/litter. Total cost for the breeding-farrowing phase was estimated to be $74.16/litter. At the nursery stage an increase in mortality rate, reduction in feed efficiency and daily gain was estimated to impact production by $6.01 / pig. Mortality rate was estimated to increase by 10.65% leading to an increase cost of $3.58 per pig for the nursery phase of production. Feed efficiency reduction observed in the study has a dollar value impact of 1.17 per pig. The ADG reduction of 25.29% compared to unaffected pigs was calculated to increase production costs by $1.26 per pig. Total economic impact of PRRS outbreak was $6.01 per pig.

For the grower-finishing phase estimated values were set for increased mortality, decreased feed efficiency, and reduction ADG. The estimated value of increase cost per PRRS affected group of pigs was $7.67 per pig.

Based on a total number of 104, 16 million nursery pigs produced per year in US, the calculated cost for this production stage was estimated to $201.34 million. Incidence rate provided by NAHMS for affected nurseries was 32.16%.

In the grow-finish segment, cost of disease based on an incidence rate of 38.1% (NAHMS) and a 100 million market hogs produced each year, was estimated to $292 million.

Based on the analysis of the NAHMS data the study estimated the economic impact of PRRS to US swine producers at $560 million, annually. By comparison, prior eradication annual losses due to classical swine fever and pseudorabies were estimated at $364.09 million and $36.27 million, respectively (49).

Researchers have looked at this subject recently and estimated the cost is even greater than this 2005 study predicted (50). This recent study estimated total cost of combined breeding and grow-finisher populations to $664 million which is a substantial increase from $560 million (50). In the 2005 study, 12% of total losses were allocated to the breeding herd segment. In the latest study, 45% of the cost is estimated for this production stage. Inclusion criteria for the study population in this economic analysis included a requirement of AIAO flow for grow-finisher pigs and restricted participation to "off-site" operation systems only. On a per pig basis, for combined nursery and finisher hogs the calculated cost for the producers is $4.67 for every pig marketed over one year period. The total cost model used in this study is slightly different from the 2005 model. The cost value is a sum of lost opportunity and increased cost of production.

Although the literature on PRRSv is very extensive, the impact of this pathogen on production is still understudied, particularly under Ontario conditions. Thus, the objectives of this thesis were the following:

1. To determine impact of the PRRS outbreak on nursery pig performance (Chapter 2) using production records from Ontario herds
2. To determine impact of the PRRS outbreak on grower-finisher pig performance (Chapter 3) using production records from Ontario herds
3. To estimate cost of PRRS outbreaks on the nursery and finisher sectors of the Ontario swine industry (Chapter 4)

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# CHAPTER 2: THE PRODUCTION PERFORMANCE OF NURSERY PIGS BEFORE AND AFTER AN OUTBREAK OF PORCINE REPRODUCTIVE AND RESPIRATORY SYNDROME (PRRS)

*Written in the style of Canadian Veterinary Journal*

## 2.1 Abstract

The impact of porcine reproductive and respiratory syndrome (PRRS) on three major production parameters in nursery pig populations was investigated. Data were collected from nurseries of 6 production systems before and after a PRRS outbreak. Three periods were examined: 6 months prior to the outbreak, 6 months immediately following the outbreak and the 7 to 12 month period following the outbreak. Descriptive statistics of outcome variables in all nurseries were calculated. Significant increases in mortality and reduced average daily gain (ADG), as well as higher feed conversion rates (FCR) were observed for the first 6 months post-outbreak.

The type of pig flow was a factor in recovery and influenced the parameters in the 7- 12 month post infection period. Performance was positively influenced by all-in/all-out flow by site in contrast to continuous flow production.

## 2.2 Introduction

Porcine reproductive and respiratory syndrome (PRRS) is regarded as the most important disease of swine worldwide. Clinical signs include reproductive failure and severe respiratory disease associated with pneumonia, decreased growth rate, and increased mortality. The impact of PRRS virus (PRRSv) infection is dependent on the presence or absence of other diseases in the herd, as well as environmental and management factors. The virus has the ability to induce prolonged viremia in susceptible pigs leading to persistent herd infection (1). Initial infection in naïve herds leads to a rapid spread of disease. Sow herds frequently report low reproductive performance and high neonatal mortality that can persist for 1-4 months or longer. When reproductive parameters return to normal in the sow herd endemic disease may persist in the nursery.

The impact may vary from herd-to-herd due to management and housing differences as well as a wide variation in the virulence of PRRSv strains. The most quoted study regarding the economic impact of PRRS infection in American swine herds (2) describes the impact on growth to be as high as 95g/day, mortality increased to 10.65% and a feed efficiency reduced such that a pig eats 180 g more for each kg of gain in body weight. This American study was based on data collected from only two nursery herds. Canadian production, including pig population demographics, climate, management, and PRRSv strains may be different from the US and yet there are few studies that document the impact of PRRS infection on nursery pig performance in Canada.

The objective of this study was to determine the effect of a PRRS outbreak on nursery pig performance using production records from Ontario herds with confirmed PRRS outbreak.

## 2.3 Method and materials

Six off-site nursery systems (6 different companies) located in Ontario were included in this study. The selection criteria included the presence of accurate and detailed production records and a documented outbreak of PRRS that was confirmed by a veterinarian with laboratory diagnostic evidence. The 6 nursery systems were identified as A, B, C, D, E, and F. Each farm system consisted of multiple barns. Production records were based on weekly groups of pigs entering a nursery and remaining together for a period of approximately 7 weeks. One of these weekly groups of pigs entering the nursery is referred to in this study as a “batch”. For this study, we examined the nursery production records for each system in three 6-month periods representing the period before the outbreak of PRRS, the 6-month period immediately following the PRRS outbreak and the 7-12 month period after the outbreak. Records were missing in System C for the 7-12 month period and in System D for the pre-outbreak period. The size of the systems varied and so the number of batches were different from one system to another.

*2.3.1 System A*

System A consisted of 2 farrowing operations of 1,500 sows each providing a weekly fill of approximately 1,300 comingled nursery pigs. Total nursery capacity was 15,800 pigs located on 7 separate sites. The nurseries were managed as all-in/all-out (AIAO) by site. Prior to the outbreak, the PRRS status of the entire System A, including the nursery sites was considered negative. Production data from 68 batches were used in the analysis (Table 2.1).

*2.3.2 System B*

System B consisted of a single 800-sow farrowing herd providing pigs for a single nursery. Pig flow was continuous flow (CF) for the site but AIAO by room. Prior to the outbreak, the PRRS status of the entire System B was considered negative. For the 18-month period of the study, a total of 38 batches of pigs were placed in the nursery. At one point, during the post-outbreak period the nursery was depopulated.

*2.3.3 System C*

System C consisted of a 2,300-sow farrowing operation providing pigs for 3 nurseries (2,000, 4,000 and 3,400 head capacity). Pig flow was CF for the sites, but AIAO by room. Prior to the outbreak, the PRRS status of the entire System C was considered negative. A total of 13 batches were followed throughout 12-months of the study (6 months before and 6 months after) (Table 2.1).

*2.3.4 System D*

System D consisted of a single newly established 2,200-sow farrowing herd providing pigs for 2 nurseries with a combined capacity of 8,800 pigs, operated as AIAO by site. Prior to the PRRS outbreak the health status was unknown. Production records of 6 batches were used in this study, but no records for the pre-outbreak period were available.

*2.3.5 System E*

System E consisted of a 750-sow farrowing unit supplying pigs to a single nursery. The nursery was CF and designed to handle batches of 2,000 pigs. Prior to the outbreak, the PRRS status of the sow herd and the nursery was considered negative. In the 18-month period of time under study the performance of 8 batches were recorded (Table 2.1).

*2.3.6 System F*

System F consisted of a single 1,500 sow farrowing operation. Pigs were sent to an off-site nursery with a 4,200 head capacity. The nursery was CF with AIAO by room. Prior to the outbreak, the PRRS status of the sow herd and the nursery was considered positive but stable. In the 18-month period of time the performance of 16 batches were included (Table 2.1).

## 2.4 Statistical analysis

Data were analyzed using descriptive statistics by summarizing the three outcome variables over different PRRSv periods. For mortality, Poisson regression with random effect of production system and nursery barn was used. For average daily gain and feed conversion ratio, a linear mixed model with random effect of production system and nursery barn was used. Regression models were fitted in the same way for all three outcomes. First, univariable regression was used to evaluate statistical significance of each possible risk factor. Second, the regression model with PRRS period and one other risk factor was considered. Third, regression models with interaction between PRRS period and the other risk factor was considered. Fourth, the final model was selected on the basis of statistical significance and AIC statistics. Coefficients were transformed and interpreted as relative risks for Poisson regression, or on a natural scale for linear regression. Statistical significance was considered at the 5% level ($P < 0.05$).

**2.5 Results**

The ADG, FCR, and mortality in all batches of nursery pigs over three distinct periods: 6 months prior to PRRS outbreak, 0-6 months after PRRS outbreak, and 7-12 months after the PRRS outbreak and stratified by farm system are presented in Table 2.1, and summarized over all systems and presented in Table 2.2. Overall mortality and growth rate were worse in the two post-PRRS outbreak periods, compared to the pre-outbreak period, whereas FCR remained similar to the pre-outbreak period (Table 2.2). Factors determined to be univariably associated with mortality, feed efficiency and growth are presented in Table 2.3. Estimates from the final multivariable model for mortality and for ADG are presented in Table 2.4. The final models for mortality and ADG revealed statistically significant effect of pig flow, PRRS period and the interaction between the type of flow and the PRRS period ($P<0.001$) (Table 2.4). The interaction effect indicated that, the time since the start of the PRRS outbreak had different effect on the mortality and ADG in CF and AIAO type of nurseries. As an aid in interpretation of coefficients, a table of contrasts was constructed in which estimates from specific time periods were compared (Table 2.5). From this table, it can be inferred that the risk of mortality in the first 6 months after the outbreak in AIAO system was 1.32 times higher than during the 6 months prior to the outbreak (Table 2.5, RR=1.32, $P<0.001$, 95% CI: 1.24, 1.41) . In the 7-12 months post-outbreak period, the risk of mortality in the AIAO system is decreased by a factor of 0.72 (Table 2.5, RR=0.72, P<0.001, 95% CI: 1.61 – 1.85). In other words, 7-12 months after a PRRS outbreak nursery mortality rates are lower than they were before the outbreak in the AIAO systems. In contrast to this, the risk of mortality increased in systems using continuous flow (CF) by site in the first 6 months relative to the outbreak period (RR=1.73, Table 2.5), and increased even further in the second 6 month period (RR=2.16, Table 2.5).

The difference between CF and AIAO by site in the first 6-month period post-outbreak shows an increased risk of mortality by 1.60 compared to CF (Table 2.5). In the next period (7-12 months post-outbreak) the mortality risk is 3.65 times higher in CF compared to AIAO by site (Table 2.5).

In the pre-outbreak period, data suggest that there is no significant inference of type of flow relative to growth rate (Table 2.5, *P*=0.99). Likewise in the first 6 month period post-outbreak there is no difference in growth rate between CF nurseries and AIAO facilities (Table 2.5, *P*=0.86). Growth rate was lower in CF nurseries compared to AIAO nurseries in the 7-12 month post-outbreak period (Estimate = -69.68 g/day; *P* < 0.01, 95% CI: -114.85, -14.85, Table 2.5). Comparisons of ADG in different periods using the table of contrasts from the final multivariable model (Table 2.5) indicated the same pattern as for the mortality. This could also be discerned from the table of descriptive statistics (Table 2.6). Systems using AIAO pig flow experienced a decreased ADG in the first 6 months post-outbreak compared to pre-outbreak values. In the same type of flow, data suggest a rebound of values surpassing those recorded in the pre-outbreak period (Table 2.6). In CF systems, growth was slower in the first and second 6-month period post-outbreak compared to pre-outbreak performance, with the second 6 month post-outbreak period being worse than the first period. A summary of the differences in overall performance by period of time and by pig flow is presented in Table 2.6. Identical pattern could be observed for the FCR (Table 2.6), although no variables showed statistically significant associations with the FCR.

## 2.6 Discussion

Mortality increased in the 6 months post-outbreak and the growth rate decreased, but the results varied between production systems. This variation may have been because of the difference in virulence of the strains of PRRS virus infecting each system, or it might have been due to management and housing factors or the presence of other diseases in some of the systems (3). Various studies have shown that PRRS virus destroys alveolar macrophages and reduces the pig's ability to combat secondary respiratory disease (1). For example, Thacker et al (4) have shown that *Mycoplasma hyopneumoniae* and PRRS virus act synergistically.

Feed efficiency was relatively unaffected by the PRRS outbreak. The effect of PRRS on mortality and growth in the second 6-month period post-outbreak was more pronounced in the herds with continuous flow (AIAO by room) by site, compared to the systems with AIAO by site. In the latter systems the performance in the second 6-month period was as good or better than pre-outbreak levels. Likely PRRS virus continues to circulate in CF nurseries so that by the 7-12 month post-outbreak situation, piglets are being weaned with no active PRRS immunity because they are not exposed in the farrowing room and are first encountering the virus in the nursery (5). The low mortality rates for this time period in the AIAO group suggests that in these nurseries the virus has been cleared. In the 7-12 month post-outbreak period the risk of mortality is higher than for the first 6 months for the CF systems. Continuous exposure of PRRS negative incoming pigs to the existing viremic pigs (even if the positive pigs are kept in separate rooms) is the likely explanation for the increased risk. In the first 6-month period mortality in the nursery might be lower than in the second 6-months because when the outbreak initially occurs and for several months, piglets are exposed to the virus in the farrowing rooms and the survivors are recovering when they enter the nurseries. Alternatively, it is possible that continuous flow nursery operations reach higher prevalence of infectious animals in the second 6 months, and this could lead to higher incidence of PRRS in younger pigs at the entry to nursery. It is of note that one CF nursery had to perform complete depopulation in order to improve production parameters and overall health. From case reports and disease biology, it is intuitively known that CF is not adequate system to control PRRS. This is one of the rare studies to show this effect as a statistically significant association.

In contrast to CF, pigs in the AIAO system showed lower mortality than prior to the outbreak. This could be reflection of improved immunity and lowering the number of PRRSv-positive animals at the entry to nursery. These two parameters, together with the absence of infectious pressure from older pigs in such nurseries probably lead to much slower PRRSv transmission in the second 6 months post outbreak, or even fade-out of infection in some cases.

Growth followed a similar pattern to mortality as one might expect. Pigs that survive the pneumonia associated with PRRS infection are likely to have suppressed appetites and as a consequence grow more slowly. Growth rate recovered to pre-outbreak levels or better in AIAO systems in the 7-12 month period but not in the CF systems.

The lack of impact of PRRS on feed efficiency in nursery pigs is possibly reflective of the fact that the disease causes reduced appetite but does not interfere with the digestive system, so that what feed is eaten is efficiently used. These findings are in contrast to other studies which report a decrease in feed efficiency. For example, Dee et al. (6) suggest a reduction in feed efficiency (feed-to-gain ratio from 1.77 to 1.91).

The impact of PRRS on nursery pig production parameters is similar to other studies in general. Neumann et al. (2) reported roughly 10% mortality which is similar to the mortality recorded in the second 6-month period for CF herds in this study. This American study also reported a reduced growth rate of about 95 g/d compared to the 70g/d found in the CF herds in the second 6-month period in the present study. In other words the change in production parameters that Neumann et al. (2) used were close to the worst case scenario in the Ontario study (the CF herds in the second 6-month period following a PRRS outbreak). In addition, the Neumann et al. (2) study attributed losses to feed efficiency which was not obvious in the Ontario data. Holtkamp et al. (7) have more recently calculated the cost of PRRS and reduced the costs associated with the nursery, using production changes more in keeping with the Ontario values identified in the present study.

In conclusion we may say that PRRS infection had a significant impact on production parameters in this study. The type of flow proved to be important in the aftermath of the outbreak, and recovery to pre-break values followed different patterns. Production parameters were generally better in AIAO type of flow compared to CF in all three periods of time analysed, but in particular performance in the 7-12 month period after a PRRS outbreak was better in AIAO because production returned to pre-outbreak levels compared to the CF type of nurseries where mortality and growth rate became even worse than the period immediately after the disease occurred.

More studies are necessary to complete the real dimension of PRRS impact by adding covariants to the analysis. These covariants could include the number of attrition pigs, cost of medication and veterinary services, virus type, and demographic description of farms. The complexity of data involved in such an analysis will require multiple independent studies.

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Table 2.1: The mean (±standard deviation) for average daily gain (ADG) (g/d), feed conversion ratio (FCR), and mortality (%) in nursery pigs from 6 farm systems (A-F) over three distinct periods in the PRRS outbreak: 6 months prior to outbreak (-6mo), 6 months after the outbreak(+6mo), and 7-12 months after the outbreak (7-12mo) (N=number of batches).

| | A | | | B | | | C | | D | | E | | | F | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Parameter** | **-6mo** | **+6mo** | **7-12mo** | **-6mo** | **+6mo** | **7-12mo** | **-6mo** | **+6mo** | **+6mo** | **7-12mo** | **-6mo** | **+6mo** | **7-12mo** | **-6mo** | **+6mo** | **7-12mo** |
| N | 13 | 34 | 21 | 13 | 13 | 12 | 8 | 5 | 3 | 3 | 3 | 2 | 3 | 6 | 6 | 4 |
| ADG | 428.0 ±71 | 397.4 ±50 | 434.1 ±23 | 405.8 ±16 | 382.8 ±32 | 348.7 ±34 | 448.9 ±23 | 392.2 ±37 | 434.0 ±49 | 505.7 ±62 | 484.7 ±17 | 467.5 ±21 | 382.0 ±23 | 478.1 ±6 | 394.1 ±6 | 428.5 ±26 |
| FCR | 1.60 ±0.17 | 1.60 ±0.12 | 1.62 ±0.13 | 1.72 ±0.1 | 1.74 ±0.12 | 1.72 ±0.13 | 1.69 ±0.04 | 1.66 ±0.05 | 1.51 ±0.13 | 1.53 ±0.12 | 1.57 ±0.07 | 1.70 ±0.03 | 1.56 ±0.06 | 1.48 ±0.03 | 1.46 ±0.06 | 1.50 ±0.03 |
| Mortality | 3.20 ±2.32 | 3.29 ±1.81 | 2.10 ±0.74 | 1.29 ±0.56 | 6.81 ±3.19 | 11.88 ±6.31 | 1.03 ±0.43 | 4.57 ±2.25 | 2.40 ±1.08 | 0.85 ±0.23 | 1.40 ±0.46 | 1.85 ±1.19 | 6.67 ±5.35 | 3.15 ±2.87 | 4.17 ±2.05 | 2.34 ±1.96 |

Table 2.2: Descriptive statistics of average daily gain (ADG) (g/d), feed conversion ratio (FCR), and mortality (%) in all batches of nursery pigs over three distinct periods: 6 months prior to PRRS outbreak, 0-6 months after PRRS outbreak, and 7-12 months after the PRRS outbreak. (N= number of batches of nursery pigs)

| | **-6 mo**[a] | **6 mo** [b] | **7-12 mo**[c] |
|---|---|---|---|
| N | 43 | 63 | 43 |
| Mean ADG | 436 | 397 | 411 |
| Mean FCR | 1.64 | 1.62 | 1.63 |
| Mean Mortality | 2.1 | 4.1 | 5.1 |
| Median ADG | 431 | 390 | 424 |
| Median FCR | 1.65 | 1.65 | 1.61 |
| Median Mortality | 1.4 | 3.8 | 2.3 |
| SD ADG | 48 | 44 | 54 |
| SD FCR | 0.14 | 0.13 | 0.14 |
| SD Mortality | 1.9 | 2.6 | 5.7 |
| Min ADG | 290 | 314 | 279 |
| Min FCR | 1.34 | 1.35 | 1.42 |
| Min Mortality | 0.4 | 0.9 | 0.5 |
| Max ADG | 512 | 595 | 576 |
| Max FCR | 1.95 | 1.97 | 2.05 |
| Max Mortality | 8.0 | 13.5 | 23.6 |

[a] 6 months pre PRRS outbreak
[b] 6 months post PRRS outbreak
[c] 7 to 12 months post PRRS outbreak

Table 2.3: Variables determined to be univariably associated with mortality, average daily gain, and feed conversion ratio in 149 nursery batches divided by pig flow* and measured over 1.5 years in 6 large systems from Ontario

| **Covariate** | **Estimate** | **95% confidence interval** | | ***P* value** |
|---|---|---|---|---|
| **Mortality** | | | | |
| PRRS period 0 | Baseline | | | |
| PRRS period 1 | 1.61 | 1.53 | 1.69 | <0.01 |
| PRRS period2 | 1.4 | 1.32 | 1.47 | <0.01 |
| AIAO | Baseline | | | |
| CF | 1.79 | 1.18 | 2.73 | 0.007 |
| Barn capacity (below median) | Baseline | | | |
| Barn capacity (above median) | 0.35 | 0.21 | 0.62 | <0.01 |
| Weaning age (below median) | Baseline | | | |
| Weaning age (above median) | 1.25 | 1.07 | 1.45 | 0.004 |
| Sow herd size (below median) | Baseline | | | |
| Sow herd size (above median) | 0.1 | 0.99 | 0.99 | 0.03 |
| **ADG** | | | | |
| PRRS period 0 | Baseline | | | |
| PRRS period 1 | -43.43 | -60.6 | -26.3 | <0.01 |
| PRRS period 2 | -28.75 | -47.6 | -9.9 | <0.01 |
| AIAO | Baseline | | | |
| CF | -17.67 | -67.99 | 32.65 | 0.491 |
| Average Parity (Below median) | Baseline | | | |
| Average Parity (Above median) | -12.58 | -21.7 | -3.5 | 0.007 |
| Weaning age (Below median) | Baseline | | | |
| Weaning age (Above median) | -14.49 | -24.4 | -4.6 | 0.004 |

*AIAO-all-in/all-out by barn, CF-continuous flow by barn, but including all-in/all-out by room

Table 2.4: Final multivariable model for mortality and for average daily gain in nursery pigs following an outbreak of porcine reproductive and respiratory syndrome

| **Model for mortality** | | | | |
|---|---|---|---|---|
| **Covariate** | **Estimate Risk Ratio** | **95% confidence Interval** | | ***P*-value** |
| CF | 1.23 | 0.81 | 1.88 | 0.34 |
| Period 1 | 1.32 | 1.24 | 1.41 | <0.001 |
| Period 2 | 0.72 | 0.67 | 0.79 | <0.001 |
| CF*period 1 | 1.30 | 1.18 | 1.44 | <0.001 |
| CF*period 2 | 2.97 | 2.66 | 3.32 | <0.001 |
| N observations = 149, Wald chi sq = 787.20, df = 5. *P*<0.01 | | | | |
| **Model for average daily gain (g/day)** | **Estimate** | **95% confidence interval** | | ***P*-value** |
| CF | 0.17 | -44.67 | 45.00 | 0.994 |
| Period 1 | -36.66 | -58.47 | -14.85 | 0.001 |
| Period 2 | 6.09 | -19.01 | 31.19 | 0.634 |
| CF*period 1 | -3.99 | -36.34 | 28.37 | 0.809 |
| CF*period 2 | -69.85 | -104.95 | -34.74 | <0.001 |
| Intercept | 449.15 | 416.90 | 481.40 | <0.001 |
| N observations = 149, Wald chi sq = 49.66, df = 5. *P*<0.01 | | | | |

Table 2.5: Contrasts based on the final multivariable regression models for nursery pigs comparing estimated difference in mortality and average daily gain (ADG) in different periods of a PRRSv* outbreak in systems using all-in/all-out (AIAO) pig flow by site compared to systems using continuous flow( CF) pig flow.

| Flow | Baseline Period | Flow | Comparison Period | Estimate RR | 95% CI | | *P*-value |
|---|---|---|---|---|---|---|---|
| **Mortality** | | | | | | | |
| AIAO | 6 months prior to break | CF | 6 months prior to break | 1.23 | 0.80 | 0.81 | 0.340 |
| AIAO | 0-6 months | CF | 0-6 months | 1.60 | 1.05 | 2.44 | 0.028 |
| AIAO | 6-12 months | CF | 6-12 months | 3.65 | 2.39 | 5.58 | <0.001 |
| AIAO | 6 months prior to break | AIAO | 0-6 months | 1.32 | 1.24 | 1.41 | <0.001 |
| AIAO | 6 months prior to break | AIAO | 6-12 months | 0.72 | 0.67 | 0.79 | <0.001 |
| CF | 6 months prior to break | CF | 0-6 months | 1.73 | 1.61 | 1.85 | <0.001 |
| CF | 6 months prior to break | CF | 6-12 months | 2.16 | 2.01 | 2.31 | <0.001 |
| **ADG** | | | | | | | |
| AIAO | 6 month prior to break | CF | 6 months prior to break | 0.17 | -44.67 | 45.00 | 0.994 |
| AIAO | 0-6 months | CF | 0-6 months | -3.82 | -47.32 | 39.68 | 0.863 |
| AIAO | 6-12 months | CF | 6-12 months | -69.68 | -114.85 | -24.50 | 0.003 |
| AIAO | 6 months prior to break | AIAO | 0-6 months | -36.66 | -58.47 | -14.85 | 0.001 |
| AIAO | 6 months prior to break | AIAO | 6-12 months | 6.09 | -19.01 | 31.19 | 0.634 |
| CF | 6 months prior to break | CF | 0-6 months | -40.64 | -64.54 | -16.74 | 0.001 |
| CF | 6 months prior to break | CF | 6-12 months | -63.75 | -88.30 | -39.21 | <0.001 |

*PRRSv –porcine reproductive and respiratory syndrome virus

Table 2.6: A comparison in performance values for nursery pigs before and after an outbreak of porcine reproductive and respiratory syndrome (PRRS) between farms using continuous flow and farms using all-in/all-out management by site.

| | **Continuous Flow Nurseries** | | | **All-in/all-out Flow Nurseries** | | |
|---|---|---|---|---|---|---|
| | **6 month pre-PRRS outbreak** | **0-6 month post-PRRS outbreak** | **6-12 month post-PRRS outbreak** | **6 month pre-PRRS outbreak** | **0-6 month post-PRRS outbreak** | **6-12 month post-PRRS outbreak** |
| Mortality (%) | 2.01 | 5.97 | 10.49 | 2.39 | 3.38 | 1.95 |
| Difference in mortality from pre-PRRS | | +3.96 | +8.45 | | +0.99 | +0.44 |
| Average daily gain (g/d) | 430 | 394 | 360 | 436 | 399 | 443 |
| Difference in growth rate from pre-PRRS (g/d) | | -36 | -70 | | -37 | +7 |
| Estimated difference in weight at end of nursery period | 21.5 | -1.8 | -3.5 | 21.8 | -1.98 | +0.35 |
| Feed conversion rate (FCR) | 1.66 | 1.69 | 1.67 | 1.64 | 1.60 | 1.61 |
| Difference in FCR from pre-PRRS | | +0.03 | +0.01 | | -0.04 | -0.03 |

# CHAPTER 3: THE PRODUCTION PERFORMANCE OF GROWER-FINISHER PIGS BEFORE AND AFTER AN OUTBREAK OF PORCINE REPRODUCTIVE AND RESPIRATORY SYNDROME (PRRS)

*Written in the style of Canadian Veterinary Journal*

## 3.1 Abstract

The effect of an outbreak of porcine reproductive and respiratory syndrome (PPRS) on mortality, feed conversion ratio (FCR), and average daily gain (ADG) in grower-finisher pig populations was investigated. Production data was analyzed comparing 3 different periods relative to a disease outbreak: 6 months pre-outbreak, 0-6 months after the outbreak, and 7-12 months post-outbreak. In the first 6-month period after the outbreak mortality and growth rate were negatively affected. In herds operating as all-in/all-out flow systems this negative impact continued in the 7-12 month post-outbreak period, but in continuous flow managed barns performance returned to pre-outbreak levels or better.

## 3.2 Introduction

Porcine reproductive and respiratory syndrome (PRRS) is considered to be the most economically important disease affecting pigs in Canada and worldwide (1). In the growing-finishing sector, PRRS virus infection causes pneumonia leading to reduced growth and possible death(2.) The virus is known to kill alveolar macrophages resulting in reduced respiratory immunity and invasion of secondary pathogens. Control of PRRS in grow finish stage is mostly based on a depop/ repop protocol in continuous flow type of production.

There are relatively few studies that analyze the impact of PRRS infection on production parameters under field conditions. The study most often quoted estimated the economic impact of infection to the American pig industry to be $293 million annually for grower-finisher pigs 3)2). A mean decrease in average daily gain (ADG) of 12% or 0.091 kg/d, in finishing pigs affected by PRRS infection is reported by these researchers (1). Likewise they reported that the feed conversion ratio (FCR) was negatively affected and that the mortality rate increased by 6%. It is possible that these figures for a PRRS outbreak in the United States may not reflect the Canadian situation. Virus strains differ between the two countries (5), and in addition there are differences in management and housing that may affect the impact of PRRS virus infection.

The objective of this study was to determine the effect of a PRRS outbreak on grower-finisher pig performance (mortality, average daily gain, and feed conversion ratio) using production records from Ontario herds with confirmed PRRS outbreak.

### 3.3 Materials and Methods

The analysis in this study is based on data recorded from 6 large multi-site production systems located in southwestern and central Ontario. Production systems are defined as consisting of one or more sow herds, flowing weaned pigs through off-site nurseries, and separate finishing sites. A total of 7 sow herds organized in 6 production systems were considered for this analysis. Systems were considered for inclusion into the study if: (i) the source sow herds experienced a clinical outbreak of PRRS (confirmed by diagnostic testing) between 2005 and 2011, (ii) had production records available, and (iii) were willing to participate in the study. Data from 49 finisher barns were included in the study.

Data considered for this study were based on closeout records available for groups of pigs raised at each finisher site. Typically these records included the date that pigs were introduced (fill date), the last date when pigs were sent to market (end date), number of pigs introduced, number of pigs marketed, mortality (count and percentage), ADG, and FCR.

The following variables were considered as possible risk factors: type of flow, herd size, previous PRRS virus status of a sow herd, and PRRS period. Pig flow was divided into 2 types: continuous flow (CF) and all-in/ all-out (AIAO). In CF type, new groups of pigs were placed in the barn before previous batches were shipped. In contrast, AIAO by site was characterized by the placement of pigs in empty, cleaned, and disinfected barns. Herd size was defined as large or small based on median herd size for all herds in the study. The previous PRRS virus status of a sow herd was defined on the basis of records from the herd's veterinarian including diagnostic laboratory testing.

The PRRS period was defined on the basis of the date of the PRRS outbreak in the source sow herds. The length of the study period of six month was decided based on the 6 month herd closure protocol that is commonly used in the Ontario swine industry. It is assumed that by 6 months post-break the sow herd will become "immune-stable" and viremic piglets will not be leaving the farrowing room. The first PRRS period (Period 0) was the 6 months prior to the outbreak, and this was considered as a baseline for production parameters. The second PRRS period (Period 1) was the 6 month period beginning on the day PRRS was diagnosed. The third PRRS period (Period 2) was the second 6 month period following the PRRS outbreak.

### 3.4 Statistical Analysis

Data were analyzed using descriptive statistics by summarizing the three outcome variables (mortality, ADG, and FCR) over different PRRS periods. For mortality, Poisson regression with random effect of production system and finisher barn was used. For ADG and FCR, linear mixed model with random effect of production system and finisher barn was used. Regression models were fitted in identical ways for all three outcomes. First, univariable regression was used to evaluate statistical significance of each possible risk factor. Second, a regression model with PRRS period and one other risk factor was considered. Third, regression models with interaction between PRRS period and other risk factors were considered. Fourth, the final model was selected on the basis of statistical significance and AIC(Akaike Information Criteria) statistics. Finally, final models were interpreted and residual diagnostics were performed at different levels (ie, batch, finisher site, and system). Results were interpreted as relative risks for Poisson regression, or on a natural scale for linear regression. Statistical significance was considered at the 5% level ($P < 0.05$).Data was analysed using STATA.

### 3.5 Results

Descriptive statistics for ADG, FCR and mortality for pre and post-outbreak periods on grower-finisher farms in the 6 farm systems are presented in Table 3.1. Mortality and growth rate varied more between systems than between pre-PRRS and post-PRRS periods of time. When type of flow was considered, mortality rate shows a slight increase in the first 6 months post-outbreak and even higher rates in the 7-12 months after the outbreak, for the AIAO type of flow. In CF operations, mortality is only higher in the first 6 months after the outbreak and is lower than the baseline level in the second 6-month post-outbreak period (Table 3.2, Figure 3.1). Average daily gain (ADG) follows a pattern similar to mortality rates when the type of flow is considered with lowest values recorded in the 7-12 month period post-outbreak in CF systems. All in/all out flow systems recorded lower values for ADG in the first 6 months after the outbreak, and then even still lower values for the 7-12 months whereas CF barns recorded improved growth in the 7-12 month post-outbreak period (Table 3.2, Figure 3.2). Feed conversion ratio (FCR) was only slightly affected by the PRRS outbreak overall (Table 3.2, Figure 3.3).

In the three final multivariable models for mortality, ADG, and FCR, there was significant interaction between the PRRS period and the type of pig flow ($P$<0.01; Table 3.3). As an aid in the interpretation of final models, contrasts that compared estimates from relevant PRRS periods were constructed (Table 3.4). In the final model for mortality, the rate of average batch mortality in the first 6 months of the outbreak, in comparison to the baseline mortality in the same type of flow, was numerically increased but not statistically significant in the AIAO system (RR=1.01; $P$=0.91; Table 3.4), and was 1.12 times higher in the CF system (RR=1.12, $P$=0.009; Table 3.4). In the final model for mortality, the rate of average batch mortality in the second 6 months of the outbreak (ie 7 – 12 months), in comparison to the baseline mortality in the same type of flow, was increased and statistically significant in the AIAO system (RR=1.07; $P$=0.033; Table 3.4), and was 0.85 times lower in the CF system (RR=0.85, $P$=0.001; Table 3.4). Similar patterns were observed for average daily gain (Table 3.4) and for feed conversion ratio (Table 3.4). For example, batches of pigs within CF system are expected to have 47.8 g/day lower average daily gain during the first 6 months of outbreak than before the outbreak (Table 3.4, $P$=0.028). However, for the feed conversion ratio, none of the relevant comparisons between PRRS periods for the feed conversion ratio were statistically significant ($P$>0.08). The variation in mortality, ADG, and FCR in CF and AIAO for the 3 PRRS time periods are illustrated in Figures 3.1, 3.2 and 3.3, respectively.

**3.6 Discussion**

Overall, the change in performance after the PRRS outbreak in the finisher phase was less than what American studies have reported (3, 4). In the present study, ADG decreased from 863g/d to 822g/d and 833g/d for the first and second 6-month period post-outbreak. Neumann et al. (3) suggested a 90g per day decrease and this is less than half of that. Neumann et al. (3) also suggested a negative impact to feed efficiency but the feed conversion ratio remained at 2.7 before and after the outbreak, and statistically significant differences between the relevant periods could not be detected for FCR. In a controlled experimental challenge study the gain to feed ratio in grower pigs not affected by PRRS was 0.46 compared to 0.39 for pigs experimentally infected with PRRS virus (5). Mortality did increase from 5% to 5.7% and 6.2% for the first and second PRRS periods, respectively, but these figures are considerably lower than the increase in mortality reported by Neumann et al. (32). Using the baseline for the current study Neumann et al. (32) would have predicted an increase to over 11% mortality in the post-outbreak period. It is possible that the strains of PRRS involved in this Ontario study are of lower virulence than those strains affecting the American herds in the Neumann et al.(3) study. Other factors such as housing and management and the presence of other diseases likely also influenced the impact of the infection (1).

It is worth noting that there was considerable variation in the effect of PRRS from system to system. The flow of pigs appeared to affect the impact of PRRS, particularly in the 7-12 month post-outbreak period. When grower-finisher barns were managed as CF, performance appeared to return to baseline levels or even better in the 7-12 month post-outbreak period compared to the AIAO barns where performance continued to be worse than pre-outbreak and possibly worse than the first 6 months after the PRRS outbreak.

There are certain limitations to the current study. Firstly, this is a retrospective study and herds were selected because they kept good production records and had experienced a PRRS outbreak. Retrospective studies can be problematic because the data were collected for a different purpose and not specifically for the study. Even though good records were kept, there is always a possibility of errors, especially on farms with continuous flow. Inaccurate inventory counts of pigs or feed are always possible on these types of farms. For example the FCR for CF farms appeared to be more variable than the AIAO farms possibly reflecting the difficulty in accurately measuring this parameter on CF grower-finisher farms. In addition, these farms weren't randomly chosen and therefore may not be representative of the overall Ontario pig population. Secondly, the method by which an outbreak was defined may have influenced the results. It was assumed that once the disease was diagnosed in the sow herd that the disease would rapidly spread through the other stages of production because PRRS virus is highly transmissible (1), but in this study there was no confirmation of when PRRS broke in the grower-finisher barn.

This study was limited to grower-finisher barns that received pigs initially from a PRRS negative source and then received pigs from the same source after a PRRS outbreak. Except for the first month or two after the outbreak when the PRRS virus was possibly being introduced to populations of seronegative grower-finisher pigs, the following months would have represented batches of seropositive pigs entering the grower-finisher barn, or eventually PRRS negative pigs entering a clean empty barn in the case of AIAO production. In other words often batches of pigs were entering the grower-finisher stage either after having been exposed to the virus and possibly having developed immunity, or batches of pigs produced by immune sow herds and remaining PRRS negative. The introduction of a highly virulent PRRS virus to an immunologically naive grower-finisher herd would cause much more severe disease than what most of the batches in this study experienced. There were batches that did have mortality over 10% and growth rate greatly reduced, possibly reflective of the scenario of PRRS virus infecting an immune-naive population, but the number of batches that were severely affected was small.

The actual pattern of production parameters during three stages of PRRS outbreak was dependent on the type of flow. In AIAO flow, the production parameters over the two 6-month post-outbreak periods were worse than the pre-outbreak baseline. A possible explanation for this is that by 7 months post-outbreak most of the pigs are leaving the farrowing rooms with passive immunity and no PRRS virus and the overall population is PRRS virus-negative and serologically negative when they enter the grower-finisher barn but a few viremic pigs are present and creating an outbreak in a largely naive population. A recent study (7) looked at the time to stability from PRRSv and time to return to previous production parameters following vaccination with LMV and LFV (autogenous).TTS (time to stability was on average 26.6 weeks and time to performance recovery was 16.5 weeks (range 0-29).This analysis does not take in consideration type of flow in their models assuming all in all out (AIAO) as unique type of flow. In contrast, in CF barns the production parameters were improved in the second 6-month post-outbreak period. The most likely explanation for this phenomenon is that pigs in CF barns are likely being exposed in the nursery and when they enter the grower stage they are recovering and have immunity.  At this stage the study population of this analysis may be categorised as II-B, positive stable undergoing elimination (8).

Overall, the decrease in growth rate and feed efficiency, and the increase in mortality in these Ontario grower-finisher herds were less than previously reported in American studies (34). Both CF and AIAO type of barns suffered losses in the first 6-month period after a PRRS outbreak, but only in AIAO barns did the decreased performance continue for the next 6-month period.

### 3.7 References


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Table 3.1: Descriptive statistics of average daily gain (ADG) (g/d), feed conversion ratio (FCR), and mortality (%) in all batches of grower-finisher pigs over three distinct periods: 6 months prior to PRRS outbreak (1), 0-6 months after PRRS outbreak (2), and 7-12 months after the PRRS outbreak (3). (N= number of batches of grower-finisher pigs)

| Farm | Period | ADG Mean±SD | FCR Mean±SD | Mortality Mean±SD | N |
|---|---|---|---|---|---|
| A | 1 | 842±54 | 2.69±0.20 | 7.6±3.6 | 20 |
| A | 2 | 799±87 | 2.73±0.16 | 7.3±3.8 | 36 |
| A | 3 | 792±82 | 2.75±0.15 | 7.9±4.6 | 30 |
| B | 3 | 919±21 | 2.74±0.11 | 2.9±1.3 | 2 |
| C | 1 | 874±42 | 2.72±0.13 | 1.9±0.4 | 11 |
| C | 2 | 862±47 | 2.76±0.15 | 2.3±1.0 | 10 |
| C | 3 | 924±23 | 2.66±0.10 | 2.7±1.3 | 11 |
| D | 1 | 839±31 | 2.80±0.09 | 3.0±0.9 | 12 |
| D | 2 | 895±49 | 2.72±0.10 | 3.1±1.6 | 9 |
| E | 1 | 866.0 | 2.65 | 4.7 | 1 |
| E | 2 | 765±71 | 2.96±0.22 | 6.6±0.4 | 2 |
| E | 3 | 813.0 | 2.73 | 8.7 | 1 |
| F | 1 | 862±22 | 2.91±0.15 | 6.2±1.9 | 4 |
| F | 2 | 799±36 | 2.83±0.08 | 5.5±2.7 | 4 |
| F | 3 | 858±7 | 2.86±0.06 | 1.8±0.7 | 2 |
| combined | 1 | 863±48 | 2.74±0.17 | 5.0±3.5 | 48 |
| combined | 2 | 822±82 | 2.75±0.15 | 5.7±3.7 | 61 |
| combined | 3 | 833±89 | 2.73±0.14 | 6.2±4.5 | 46 |

Table 3.2: A comparison in performance values for grower-finisher pigs before and after an outbreak of porcine reproductive and respiratory syndrome (PRRS) between farms using continuous flow and farms using all-in/all-out management by site.

| | **All-in/All-out** | | | **Continuous Flow** | | |
|---|---|---|---|---|---|---|
| | **6 months pre-PRRS outbreak** | **0-6 months post-PRRS outbreak** | **7-12 months post-PRRS outbreak** | **6 months pre-PRRS outbreak** | **0-6 months post-PRRS outbreak** | **7-12 months post-PRRS outbreak** |
| Mortality (%) | 5.47 | 6.1 | 7.26 | 4.13 | 4.74 | 3.35 |
| Difference in mortality from pre-PRRS period | | 0.63 | 1.79 | | 0.61 | -0.78 |
| Average daily gain(g/d) | 870 | 828 | 815 | 849 | 802 | 876 |
| Difference in growth rate from pre-PRRS(g/d) | | -45 | -55 | | -47 | +27 |
| Difference in days taken to reach market weight | | 5 | 7 | | 6 | -4 |
| Feed conversion rate | 2.69 | 2.72 | 2.73 | 2.81 | 2.84 | 2.70 |
| Difference in FCR from pre-PRRS | | 0.03 | 0.04 | | 0.03 | -0.11 |

Table 3.3: Final multivariable model for mortality, average daily gain ADG) and feed conversion ratio (FCR) in grower-finisher pigs following an outbreak of porcine reproductive and respiratory syndrome.

| **Model for mortality** | **Risk Ratio** | **95 % Confidence** | | ***P*-value** |
|---|---|---|---|---|
| AIAO Flow | 1.02 | 0.75 | 1.36 | 0.907 |
| 6 months after | 1.12 | 1.03 | 1.22 | 0.009 |
| 7-12 months after | 0.84 | 0.76 | 0.92 | 0.001 |
| 6 months after*AIAO | 0.89 | 0.81 | 0.99 | 0.037 |
| 7-12 months after*AIAO | 1.26 | 1.13 | 1.41 | <0.005 |
| **Model for ADG** | **Coef.** | **95 % Confidence** | | ***P*-value** |
| AIAO Flow | 49.31 | 6.25 | 92.35 | 0.025 |
| 6 months after | -47.84 | -90.56 | -5.11 | 0.028 |
| 7-12 months after | 14.87 | -29.34 | 59.08 | 0.511 |
| 6 months after*AIAO | 18.96 | -32.05 | 69.96 | 0.466 |
| 7-12 months after*AIAO | -50.64 | -104.38 | 3.09 | 0.065 |
| Intercept | 840.34 | 792.78 | 887.89 | <0.005 |
| **Model for feed conversion ratio (FCR)** | **Coef.** | **95 % Confidence** | | ***P*-value** |
| AIAO Flow | -0.15 | -0.25 | -0.07 | <0.005 |
| 6 months after | 0.03 | -0.06 | 0.13 | 0.498 |
| 7-12 months after | -0.09 | -0.19 | 0.1 | 0.078 |
| 6 months after-AIAO | 0 | -0.12 | 0.11 | 0.953 |
| 7-12 months after-AIAO | 0.15 | 0.03 | 0.28 | 0.016 |
| Intercept | 2.85 | 2.76 | 2.94 | <0.005 |

Table 3.4: Contrasts based on the final multivariable regression models for finisher pigs comparing estimated difference in mortality, average daily gain (ADG) and feed conversion ratio (FCR) in different periods of a PRRSv outbreak in systems using all-in/all-out (AIAO) pig flow by site compared to systems using continuous flow( CF) pig flow.

| **Mortality** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Flow** | **Baseline Period** | **Flow** | **Comparison Period** | **Estimate RR** | **95%CI** | | ***P*-value** |
| CF | 6 months prior | CF | 0-6 months | 1.12 | 1.02 | 1.21 | 0.009 |
| CF | 6 months prior | CF | 7-12 months | 0.85 | 0.79 | 0.92 | 0.001 |
| AIAO | 6 months prior | AIAO | 0-6months | 1.01 | 0.95 | 1.03 | 0.910 |
| AIAO | 6 months prior | AIAO | 7-12months | 1.07 | 1.01 | 1.14 | 0.033 |
| **ADG** | | | | | | | |
| **Flow** | **Baseline Period** | **Flow** | **Comparison Period** | **Estimate** | **95%CI** | | ***P*-value** |
| CF | 6 months prior | CF | 0-6 months | -47.83 | -90.55 | -5.10 | 0.028 |
| CF | 6 months prior | CF | 7-12 months | 14.86 | -29.34 | 59.08 | 0.510 |
| AIAO | 6 months prior | AIAO | 0-6 months | -28.87 | -56.84 | -0.91 | 0.043 |
| AIAO | 6 months prior | AIAO | 7-12 months | -35.77 | -66.85 | -4.68 | 0.024 |
| **FCR** | | | | | | | |
| **Flow** | **Baseline Period** | **Flow** | **Comparison Period** | **Estimate** | **95%CI** | | ***P*-value** |
| CF | 6 months prior | CF | 0-6 months | 0.030 | -0.06 | 0.13 | 0.498 |
| CF | 6 months prior | CF | 7-12 months | -0.090 | -0.19 | 0.01 | 0.078 |
| AIAO | 6 months prior | AIAO | 0-6 months | 0.030 | -0.03 | 0.09 | 0.346 |
| AIAO | 6 months prior | AIAO | 7-12 months | 0.060 | -0.10 | 0.13 | 0.096 |

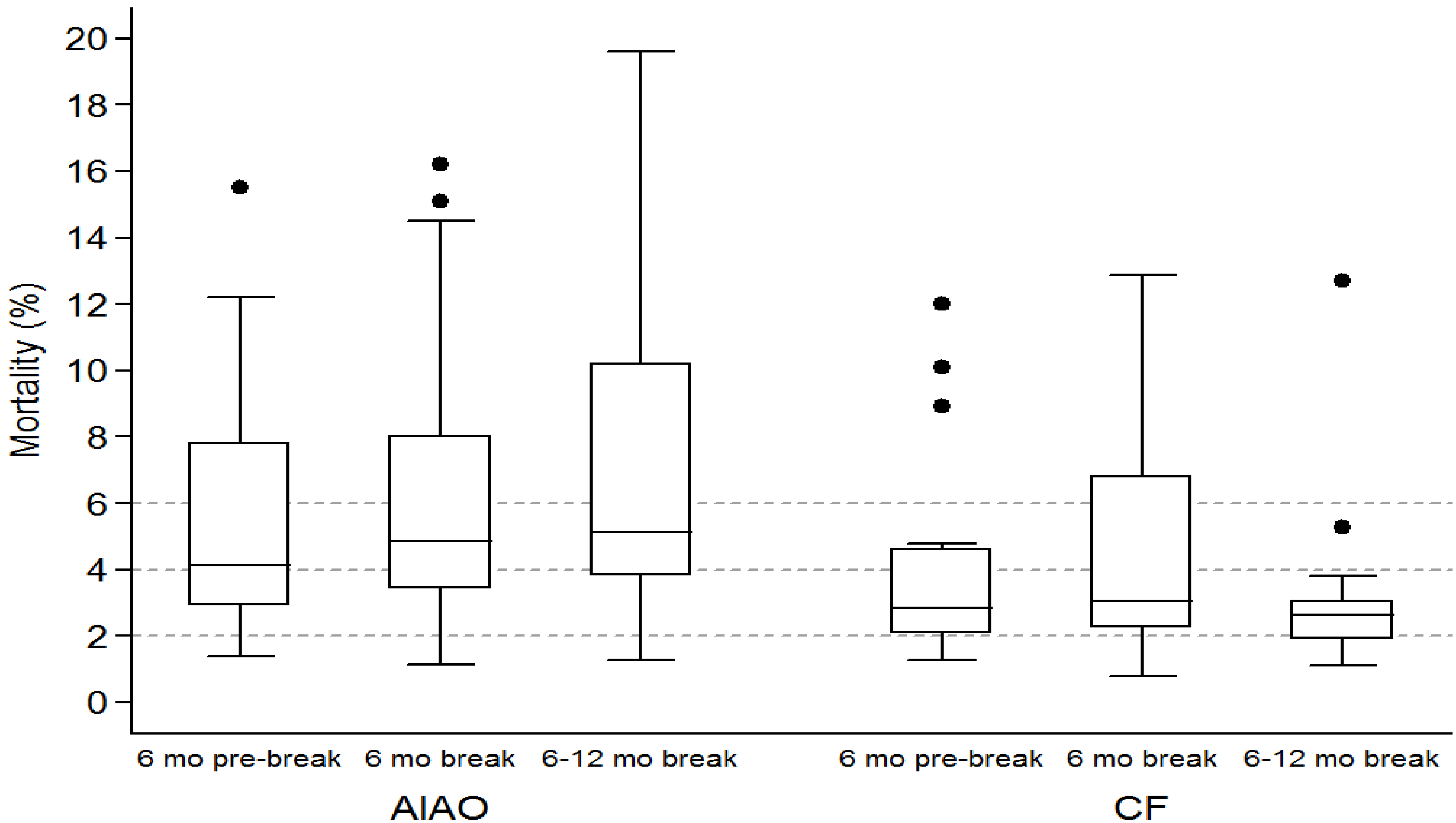


Figure 3.1: A comparison of the mortality in 3 time periods relative to an outbreak of porcine reproductive and respiratory syndrome (PRRS) in grower-finisher pigs raised in all-in/all-out (AIAO) systems and continuous flow (CF) systems

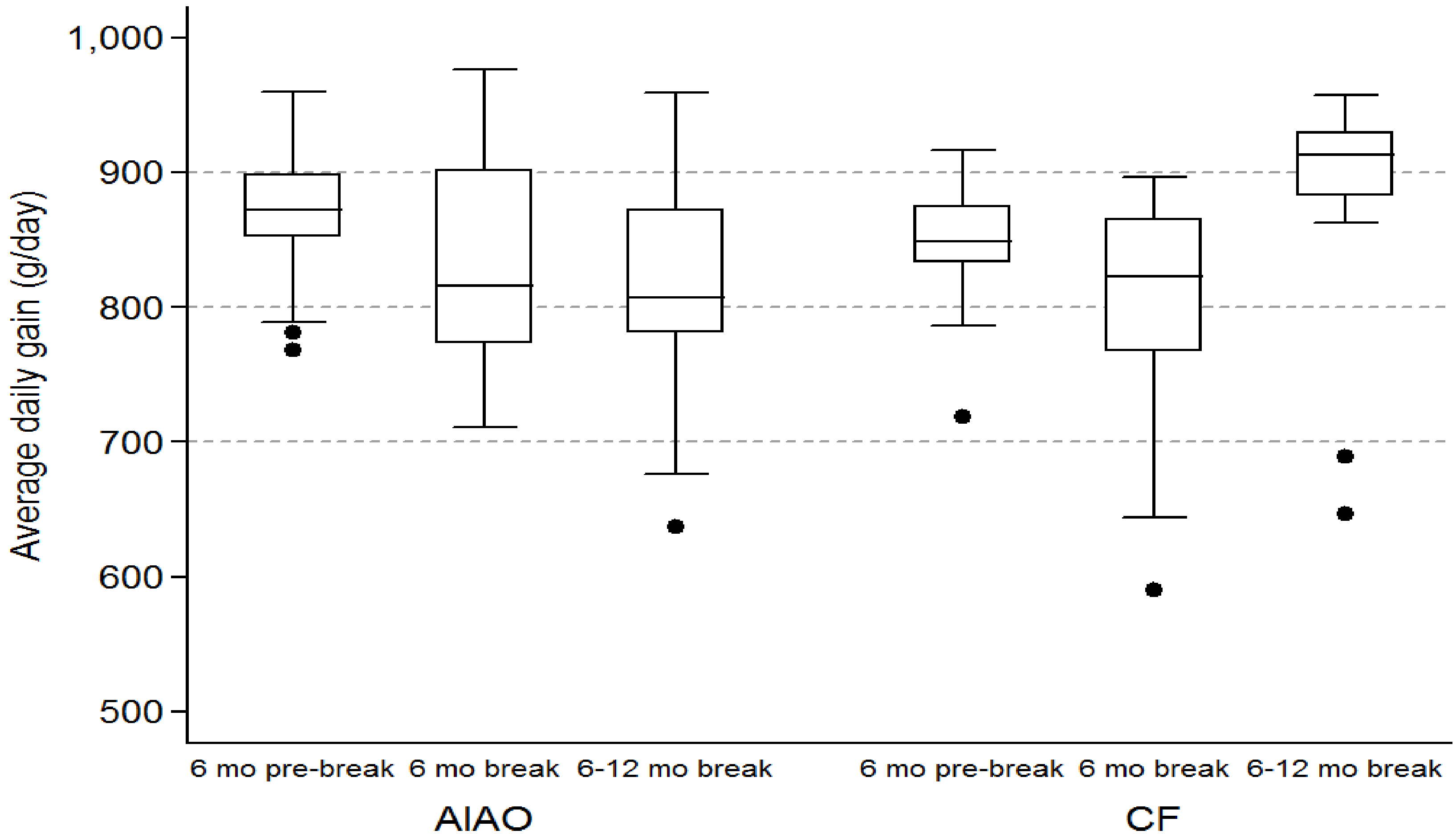


Figure 3.2: A comparison of average daily gain in 3 time periods relative to an outbreak of porcine reproductive and respiratory syndrome (PRRS) in grower-finisher pigs raised in all-in/all-out (AIAO) systems and continuous flow (CF) systems

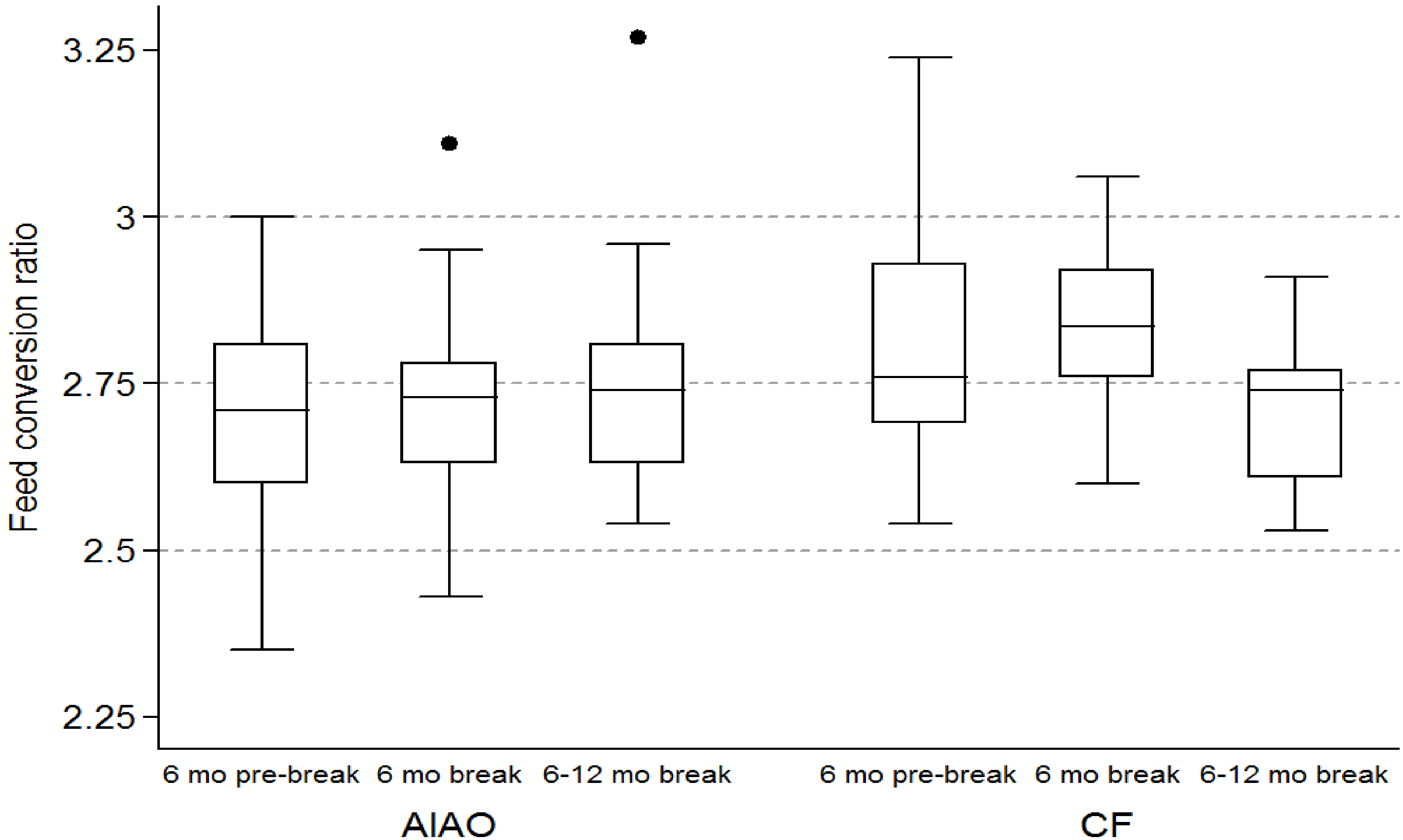


Figure 3.3: A comparison of feed conversion ratio in 3 time periods relative to an outbreak of porcine reproductive and respiratory syndrome (PRRS) in grower-finisher pigs raised in all-in/all-out (AIAO) systems and continuous flow (CF) systems

# CHAPTER 4: THE ECONOMIC IMPACT OF PORCINE REPORDUCTIVE AND RESPIRATORY SYNDROME (PRRS) ON NURSERY AND GROWER – FINSIHER PRODUCTION IN ONTARIO

## 4.1 Abstract

The objective of this economic analysis of nursery and grower-finisher data was to estimate the cost of porcine reproductive and respiratory syndrome (PRRS) with respect to the growing pig phase of production in Ontario. The change in mortality, feed efficiency and growth following a PRRS outbreak was calculated from case studies conducted on 6 farming operations and extrapolated to estimate the economic impact for the province. Incidence rate, type of pig flow, and time period with regard to PRRS infection, were considered in the creation of this stratified economic model.

It was estimated, based on a deterministic model, that on an annual basis, the increase in mortality due to PRRS in nurseries and in grower-finisher herds, costs Ontario producers $746,078, reduced feed efficiency results in a further loss of $833,976 and reduced growth rate adds another $2,307,415 in losses. The total cost to the Ontario swine industry was estimated to be almost $4 million (i.e. $3,887,469). This represents a large economic loss, but is lower than all previous published estimates and is considerably lower than estimates derived using a stochastic model based on the same data set.

**Keywords:** swine, cost, mortality, feed efficiency, growth

## 4.2 Introduction

Porcine reproductive and respiratory syndrome (PRRS) is widespread and considered to have major economic impacts on the pork industry in Ontario and worldwide. An outbreak of the disease causes a reduction in farrowing, partially as a result of abortions. Pre-weaning mortality increases during a PRRS outbreak and can remain high for months. In nursery and growing pigs, the primary effect is an increase in respiratory disease. Pigs develop an interstitial pneumonia as well as immune suppression, allowing secondary bacterial infections to occur (1). Mortality increases and growth performance is negatively impacted. In general, it is relatively easy to document the economic impact of PRRS in the sow herd by calculating the reduced number of pigs weaned in a given period of time. Losses in the post-weaning period are harder to quantify.

There is one study in the literature that is frequently cited to describe the cost of PRRS to the North American swine industry. Neumann et al. (2) reported that PRRS costs the American swine industry over $500 million per year and that over 80% of the cost is attributable to losses in production in the nursery and grower-finisher stages. This study was based on production data from a large number of sow herds but only 2 nurseries and 6 grower-finisher case herds. This study estimated an annual cost of $201.34 million for U.S. nurseries, based on 32% annual incidence rate for PRRS infection. Similarly, for the grower-finisher stage the annual cost of PRRS in the United States was estimated to be $293.23 million, based on an incidence rate of 38% per year. More recently researchers examined these calculations and re-estimated the annual cost of PRRS in the U.S. to have increased by $100 million compared to the losses in 2005 (3).

There are no similar studies that use Canadian production data from herds experiencing PRRS outbreaks to estimate the cost of this disease in Canada. It is possible that the impact of PRRS is different in Ontario compared to the U.S. because the strains of viruses in the 2 regions are different (4). In addition, the incidence rate, severity of clinical expression, and management may be different between Ontario and U.S. herds.

The objective of this study was to estimate the annual cost to the Ontario swine industry of PRRS in nursery and grower-finisher pig production.

## 4.3 Methods and Materials

### 4.3.1*General outline of the model*

In brief, the costs of a PRRS outbreak for the nursery and the grower-finisher phases were determined by combining the total cost due to increased mortality, reduced average daily gain (ADG), and changes in the feed conversion ratio (FCR) over 2 periods of 6 months each beginning at the time of an outbreak and the period 7 to 12 months after the outbreak. The cost model was stratified by the type of pig flow (all-in/all-out vs. continuous) since our previous results (see chapters 2 and 3) suggested that type of flow was an important determinant of production losses. In addition, the incidence of PRRS at the herd level was included in the cost model. As a general principle, production losses based on descriptive data from previous chapters were used and are summarized for the nursery in Table 4.1 and for the grower-finisher stage in Table 4.2. The production loss attributable to PRRS was calculated as the difference between the average production parameter during a specific phase of the outbreak (i.e. the first or the second 6-month period after the start of the outbreak) in each of the 2 flow types, relative to the baseline data for the same flow type (the 6 months prior to the outbreak). In case that the average production parameter during a specific outbreak phase was better than during the baseline period, no change in the parameter was assumed. The assumption is that PRRS cannot improve production parameters. Similarly, in stochastic models, the uncertainty was introduced by specifying the Triangular distribution (5). This distribution is commonly used to include expert opinion into stochastic models, and in this manuscript it was based on including expert opinion about the minimum, most likely and maximum values for a given parameter. For consistency, only this distribution was used regardless of the source of data. The most likely value of the Triangular distribution for each parameter was calculated by subtracting the mean production parameter in a specific PRRS period from the mean of that production parameter in the baseline parameter. The minimum value for this distribution was calculated by subtracting the minimum value during a specific outbreak period from the mean value for that period during the baseline. Similarly, the maximum value for this distribution was calculated by subtracting the maximum value during a specific outbreak period from the mean value for that period during the baseline. In case that the minimum or the maximum values were better than the mean value for the baseline, we assumed 0 for minimum or maximum for the specific Triangular distribution for a parameter under consideration

### *4.3.2 Cost of PRRS in nursery*

The number of nursery pigs produced in one year was first stratified based on the type of flow in nursery barns and then into 6-month periods. The first 6-month period was the period immediately following the start of the PRRS outbreak, and the second 6 month period was 7-12 months after the start of the outbreak. Based on a 2010 survey by Agribrands Purina there are approximately 500 nursery sites in Ontario, with 40% described as having continuous flow (CF) and 60% of nurseries with all-in/all-out (AIAO) flow (6). To calculate the cost of PRRS on nursery production it was estimated that 5,410,000 nursery pigs are produced in Ontario on an annual basis (7). It was further assumed that the annual incidence of PRRS outbreaks in Ontario is 10% (8). It was assumed that an outbreak of PRRS in a sow herd will be spread rapidly through the production system and will affect a proportional number of nursery herds.

The impact of PRRS in the first 6 months after it is first diagnosed on mortality, average daily gain, and feed conversion ratio were estimated based on descriptive statistics from data in Chapter 2, where the difference in performance was reported for the period before PRRS and for the two 6-month periods following the outbreak on case farms.

The increase of mortality due to PRRS was used to calculate the number of pigs that died due to PRRS in CF and in AIAO barns affected by PRRS over the two consecutive 6-month periods and this number was then multiplied by the cost of a single nursery pig (assumed to be $ 40). For example, total cost due to mortality in CF barns in the first 6 months was calculated as the total number of pigs entering the CF barns in the first 6 months multiplied by the incidence of PRRS times the mortality due to PRRS in the first 6 months in CF barns multiplied by the purchase price of an individual pig. Similar equations were used to calculate the cost of mortality in CF barns in the 6 to12 month period following an outbreak, and for the first and second 6 months in AIAO barns. Then, the 4 costs due to mortality were summed to give a total annual cost of nursery mortality due to PRRS for the entire Ontario industry.

The increase in FCR due to a PRRS outbreak was calculated in CF and in AIAO barns for the two consecutive 6-month periods following an outbreak. The average cost of feed for pigs in the nursery stage of production was assumed to be $0.66 per kg (7). To calculate the cost of reduced feed efficiency it was assumed pigs entered a nursery at 5 kg live weight and exited at 25 kg, thus gaining 20 kg in the nursery period. A change in the FCR of 0.1, for example from 1.5 to 1.6, would mean it would require 32 kg of feed to gain 20 kg of weight compared to 30 kg of feed and thus increase the cost of producing a pig by $1.32 per pig. Using these assumptions the cost of an increase in FCR in the first 6 months in the CF barns was calculated as: number of pigs produced in CF barns in the first 6 months, multiplied by the incidence of PRRS, times the increase in FCR in the first 6 months multiplied by $1.32. Similar equations were used to calculate the cost of increase in FCR in CF barns in the second 6 month period, and to calculate FCR costs for the first and second 6-month periods in AIAO barns. Then, all 4 costs were summed to give a total cost of reduced feed efficiency due to PRRS for nursery pigs in the entire Ontario industry.

The effect of PRRS on growth rate in the nursery was also calculated based on the descriptive statistics generated in chapter 2 for the two 6-month periods following a PRRS outbreak on case farms. It was assumed that the pigs would spend the same length of time in the nursery but slow growth would result in a lighter pig leaving the nursery. The price per kg for a feeder pig during this time period ($ 2.20) was estimated based on statistics published by the Ontario Ministry of Agriculture and Food (7).

For example, decrease in pig weight in CF barns in the first 6 months was calculated as total number of pigs produced in the first six months in CF barns multiplied by the incidence of PRRS times the duration of the nursery period (49 days), multiplied by the decrease in ADG (kg). This decrease in weight of pigs produced was then multiplied by $ 2.20. Similar equations were used for the cost of reduced growth rate in CF barns in the second 6 months and for the first and second 6 months in AIAO barns. All 4 costs due to reduced growth rate were summed to give a total cost of slower growth for nursery pigs due to PRRS in the entire Ontario industry.

Finally, total costs due to increased mortality, slower growth and reduced feed efficiency were combined to produce an estimate of the total cost of PRRS in nursery herds. In addition, cost per pig was also produced and this quantity was calculated by dividing the total cost by the number of pigs that went through nursery barns affected by PRRS over a period of 1 year.

In addition to this deterministic model, a stochastic simulation was performed (5). In this model, only parameters indicative of production losses in two periods and incidence of PRRS were assumed to be stochastic (i.e. variable), whereas all other parameters were assumed to be fixed. The summary statistics for stochastic models were produced including sensitivity analysis for parameters that were most influential in determining the extent of the total cost for the Ontario swine industry and on a per-pig basis.

*4.3.3 Cost of PRRS in grow-finish*

The number of grower-finisher pigs produced in one year was first stratified based on the type of flow in finishing barns and then into two 6-month periods (0-6 months and 7-12 months following the PRRS outbreak). There are approximately 1500 grower-finisher sites in Ontario and that about half operate as CF and half as AIAO (6). Approximately 4,800,000 market hogs are raised in Ontario on an annual basis (8). It was further assumed that mean incidence of PRRS in the Ontario industry is 10 % (9). An assumption was made that an outbreak of PRRS in a sow herd would spread through the nurseries and the grower-finisher barns in that system so that each production stage would be proportionally affected.

The impact of PRRS in the first 6 months on mortality, growth and feed efficiency were estimated as explained in the above section using estimates from case farms (Table 4.2) and described in Chapter 3.

The increase of mortality due to PRRS was used to calculate number of pigs that died due to PRRS in CF and in AIAO barns affected by PRRS over the two consecutive 6 month periods and this number was then multiplied by the cost of a single feeder pig (assumed to be $ 57) (7).

For example, total cost due to mortality in CF barns in the first 6 months was calculated by multiplying: total number of pigs produced in the first 6 months in CF barns, the estimated incidence of PRRS in Ontario, the percent mortality due to PRRS in the first 6 months in CF barns, and the purchase price of feeder pig. Similar equations were used for the cost of mortality in CF barns in the second 6-months, and for the first and second 6-months in AIAO barns. Then, all 4 costs due to mortality were summed to give a total annual cost of mortality due to PRRS in the entire grow finish population raised in Ontario.

Similarly, the cost due to the reduction in feed efficiency due to PRRS was performed for the 2 periods following an outbreak for CF and for AIAO types of flow. The price of a kg of grower ration was assumed to be \$ 0.40 (7) and a change of 0.1 in feed to gain ratio was estimated to cost \$3.60. This was based on the assumption that pigs would be growing from 25kg to 115 kg in weight (a gain of 90kg) through this period, and therefore the difference in feed consumption between 2.8 and 2.9 feed conversion ratio would be (90 x 2.9 – 90 x 2.8) 9 kg per pig. The total cost of reduced feed efficiency in the first 6 months in the CF barns was calculated by multiplying: number of pigs produced in CF barns in the first 6 months, PRRS incidence, the increase in FCR in CF in the first 6 months and multiply by \$ 3.60. Similar equations were used to calculate the cost related to reduced feed efficiency in CF barns in the second 6 months and for the first and second 6-month periods in AIAO barns. Then, all 4 costs due to reduced feed efficiency were summed to give a total annual feed cost for grower-finisher pigs due to PRRS outbreaks in Ontario.

The decrease in average daily gain due to PRRS was used to calculate the number of extra days spent in the barn, in CF and in AIAO barns affected by PRRS over the two consecutive 6 month periods. For example, based on descriptive statistics generated in Chapter 3 it was estimated that grower - finisher pigs in CF barns spent on average 6 extra days to reach market during the first 6-month period following a PRRS outbreak (Table 4.2). The cost per day to house a grower - finisher pig was assumed to be $ 0.24, excluding feed (8). Total cost associated with reduced growth for grower-finisher pigs raised in CF was then calculated using the following equation: Total number of pigs raised CF in the first 6 months period multiplied by the incidence rate of PRRS in Ontario farms multiplied by the number of extra days spent in the barn, multiplied by the cost of one day housing. Similarly the cost for reduced growth rate was calculated for CF barns for the second 6 months (0 extra days) and for AIAO flow barns for the two 6-month periods following a PRRS outbreak (5 days and 7 extra days, respectively). The total annual cost of reduced growth due to a PRRS outbreak as it pertains to the grower - finisher population of Ontario was calculated by adding the 4 totals together.

Finally, total costs due to increased mortality, decreased growth rate and poorer feed efficiency were combined to produce an estimate of the total cost of PRRS in grower-finisher pigs. In addition, cost per grower-finisher per year was calculated by dividing the total cost by the number of pigs that went through grower-finisher barns affected by PRRS.

In addition to a deterministic model, a stochastic simulation was performed. In this model, only parameters indicative of production losses in 2 periods and incidence of PRRS were assumed to be stochastic (ie. variable), whereas all other parameters were assumed to be fixed. The summary statistics for stochastic models were produced including sensitivity analysis for parameters that were most influential in determining the extent of the total cost for industry and on the per-pig basis.

## 4.4 RESULTS

*4.4.1 Demographic parameters*

Total number of pigs placed and raised through continuous flow (CF) nurseries over one year period of time was estimated to be 2,080,000 million. In AIAO systems 3,330,000 million nursery pigs were produced in one year period. Thus, brings up the total number of nursery pigs raised in all nurseries to 5,410,000 per year.

In the finishing barns managed in a continuous flow (CF) system 2,400,000 million market pigs were produced and a similar number in AIAO type facilities. Total number of pigs raised in both systems was estimated to 4,800,000 per annum.

*4.4.2 Cost calculations based on deterministic model*

*4.4.2.1 Mortality*

Firstly, the total number of pigs affected by PRRS was calculated based on 10 % incidence risk of disease in Ontario farms. This resulted in 208,000 infected nursery pigs in CF barns and 333,000 pigs infected in AIAO systems over one year period, for a total of 541,000 nursery pigs affected.

Cost of increased mortality due to PRRS infection was generated for nursery pigs raised in CF system showing an added cost of $516,672 for the industry. Those producers using AIAO type of flow had total estimated losses of $65,934 due to mortality. The total cost of mortality due to PRRS in both types of systems in nurseries was $582,606.

The total number of grower-finisher pigs affected by PRRS was calculated based on 10 % incidence risk of disease in Ontario farms. This resulted in 240,000 infected animals in CF barns over one year period and 240,000 pigs in AIAO systems. Thus a total of 480,000 finishing pigs were affected over a year.

Cost of increased mortality due to PRRS infection was generated for finishing pigs raised in CF systems showing an added cost of $53,352 for the industry. Those producers using AIAO type of flow lost an added $119,124 due to higher mortality rate. Calculated cost of increased mortality in finishing barns for both systems was $ 163,476 per annum.

*4.4.2.2 Cost of negative impact on FCR*

For the nursery segment FCR increase for CF was estimated to cost producers $62,400 per year, whereas for AIAO systems the estimated cost was $0. In the grower-finisher sector, over a one-year period of time, the estimated cost of increased FCR ratio was $391,716 and $442,260 in CF and AIAO systems, respectively. In total, the negative impact of PRRS infection on the ability to convert feed in gain in Ontario industry was estimated at $833,976**.**

*4.4.2.3 Cost of negative impact of PRRS on ADG*

At the end of the nursery phase pigs were lighter due to PRRS causing reduced growth rate. It was estimated that pigs in the CF barns weighed a total of 538,137 kg less. For the pigs produced in AIAO flow type, the estimated loss was 298,601 kg. Total cost of weight loss, estimated for both types of flows in Ontario nurseries was $1,840,825.

In the finishing stages the cost of added days to reach market weight, as a result of slow growth in PRRS infected pigs was first calculated to be $466,560.

*4.4.2.4 Cost of negative impact of PRRS overall*

A total cost for the Ontario swine industry of the negative impact of PRRS on mortality, FCR and ADG was estimated to be $2,485,831 for the nursery stage or $0.46 per pig produced.

For the grower-finisher stage, the annual cost of PRRS based on mortality, ADG and FCR was estimated to be $1,464,012 or $0.30 loss for every finishing pig produced. When both production stages were combined, the total loss was an estimated $3,949,843. Because only 10% of the herds were estimated to experience a PRRS outbreak in a year, the cost per pig from weaning to market on farms breaking with PRRS is $6.06

*4.4.2.5 Cost determined on the basis of stochastic model*

For the nursery stage, the stochastic model performed on cost of PRRS for the entire industry revealed the following results: the cost could vary from a minimum of $1,051,768 to a maximum of $18,682,820. The most likely value of financial loss was estimated at $6,074,568. Average cost per nursery pig basis was valued from a minimum $2.71 to a maximum of $13.34, with a mean value of $7.49 per pig in affected systems (Table 4.3).

For the finishing stage, the stochastic model revealed the following results for the Ontario industry: the cost could vary from a minimum of $931,272 to a maximum of $17,739,820, with the mean of $5,692,109. Average cost per finishing pig was estimated between a minimum $2.50 to a maximum of $ 14.89, with the mean value of $ 7.91 per pig in affected systems.

A sensitivity analysis for all variables was performed. The highest influence on cost estimates was attributed to PRRS incidence rate. This was followed by the cost attributed to drop in ADG due to PRRS. Mortality had a lesser influence in determining cost of disease. Similar pattern was observed for the nursery and the total finisher cost.

## 4.5 Discussion

The deterministic model generated costs attributable to PRRS that were lower than the stochastic model and lower than costs reported by previous economical analysis (2, 3). The differences between this study and American reports may be a reflection of different demographics, management protocols, incidence at the herd level and disease severity. In the present study an incidence rate of 10% was used in the calculation of cost to the industry, whereas the Neumann et al. (2) study used a 36% incidence rate. Sensitivity analysis performed in the present study revealed that incidence of PRRS is the most influential driver behind estimating the cost of disease at the industry level. Thus, an accurate measure of incidence is needed in order to refine the estimate of the cost of PRRS in Ontario. Recent efforts to control and eliminate PRRS in different projects across the country and in the USA, has generated data that may allow a better estimate of incidence rate in the near future (9). The observation that incidence rate has a strong influence on the cost to the industry also highlights the point that reducing the incidence rate of PRRS is the important step in reducing the overall losses due to PRRS. The results of this study help to justify the ongoing initiatives in the province to improve biosecurity, and disease surveillance.

One US-based study (2) estimated costs associated with a PRRS outbreak to be $6.01 and $7.67 for a nursery and a grower-finisher pig, respectively. These costs are almost identical to the estimates generated by the stochastic model, and possibly this is the better technique to estimate the costs associated with a PRRS outbreak. In the deterministic model the mean values were used and the small number of batches affected by very severe disease was generally nullified whereas the stochastic model utilized the wide range of values found in this data set and possibly better reflected the unpredictable nature of the disease. Stochastic models have been used to predict the clinical expression and spread of PRRS (10, 11) but not to model the cost of disease outbreaks in the swine population.

At the herd level, the parameter associated with the greatest added cost was growth rate followed by mortality. In the Neumann et al. study (2), mortality had the greatest impact on cost (60% of all costs) followed by FCR and ADG. The values for mortality from this American study (2) are higher than those estimated in the present study. It could be argued that the present study has under-estimated the cost of mortality by attributing the equivalent of the purchase price or the value of the pig upon entry to cover the cost of a dead pig, no matter at which stage the animal dies. Some studies have used an opportunity cost or the return the producer would have hoped to receive if the pig had survived and had been marketed. The reasoning for using the purchase price is because the farmer has at least lost that amount. The additional cost that is lost when a pig dies during the growing phase is primarily the amount of feed that the pig ate before dying and that is reflected in the FCR parameter. Using the purchase price as the cost of a dead pig avoids the issue of counting the cost of lost feed twice. Another difference in the present study compared to other studies is that this study followed outbreaks for a year whereas others have focused on the first 6-month period after an outbreak. Other studies have also failed to examine the effect of pig flow which appeared to have a major influence on production performance especially in the second 6-month period. In systems using CF in the nursery (AIAO by room), the performance was as low or even worse than in the period immediately after the break. On the other hand in systems with AIAO nurseries and grower-finisher barns performance in the nurseries returned to pre-outbreak levels in the second 6-month period after the outbreak but performance in the grower-finisher barn remained below pre-outbreak levels. One can speculate that most pigs in this grower-finisher population are immunologically naive and in batches where some viremic pigs are present there is potential for serious disease consequences, whereas in the CF systems pigs entering the grower barn have already had exposure to the virus and are immune.

There are some basic differences in housing costs, and feed costs between Canada and the United States. In general both building and feed costs are more expensive in Canada than in the United States and therefore extra days to market and poor feed efficiency would be expected to contribute more to the cost of disease in Canada compared to the United States.

Monitoring PRRS cost over a longer period of time should reflect a better image of total cost for the affected producers. This may be considered strength of this study. Another novelty of this study was explicit incorporation of the type of flow in the analysis, which was identified as an important factor for the development of production parameters in PRRS outbreaks. This study also has a number of limitations. Variables like cost of sanitation, veterinary cost including vaccines and antibiotics as well as feed and water medication cost were excluded from the model due to inconsistency of recorded data. These variables could have a significant impact on total cost of disease but are very difficult to accurately calculate. More efforts should be made in order to standardize close-outs reports across the industry to capture these financial aspects of production.

The methods for assessing the costs of disease in the swine population can be used to estimate the economic impact of other diseases. Attempts to measure disease costs are an important step in developing economically sound decisions regarding disease control and eradication.

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Table 4.1: Descriptive statistics of production parameters; average daily gain (ADG), mortality (mort) and feed conversion ratio (FCR), recorded in Ontario nursery barns, stratified by pig flow and used to estimate the cost of porcine reproductive and respiratory syndrome (PRRS).

| Flow type | Period | Batches | Mean | | | Minimum | | | Maximum | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | ADG (g/day) | FCR | Mort (%) | ADG (g/day) | FCR | Mort (%) | ADG (g/day) | FCR | Mort (%) |
| AIAO[a] | 6 months pre-outbreak | 21 | 436 | 1.64 | 2.39 | 290 | 1.34 | 0.48 | 512 | 1.95 | 8.00 |
| AIAO | 6 months post-outbreak | 42 | 399 | 1.60 | 3.38 | 314 | 1.35 | 0.95 | 595 | 1.86 | 8.20 |
| AIAO | 7 - 12 months post- outbreak | 24 | 443 | 1.61 | 1.95 | 396 | 1.42 | 0.54 | 576 | 1.86 | 3.43 |
| CF[b] | 6 months pre-outbreak | 19 | 430 | 1.66 | 2.01 | 367 | 1.44 | 0.39 | 495 | 1.91 | 5.80 |
| CF | 6 months post-outbreak | 18 | 394 | 1.69 | 5.97 | 323 | 1.40 | 1.01 | 482 | 1.97 | 13.49 |
| CF | 7 - 12 months post-outbreak | 16 | 360 | 1.67 | 10.49 | 279 | 1.48 | 2.21 | 425 | 2.05 | 23.58 |

[a]AIAO- all-in/all/out movement of nursery pigs by site
[b]CF- continuous movement of nursery pigs by site including AIAO by room

Table 4.2: Descriptive statistics of production parameters; average daily gain (ADG), mortality (mort) and feed conversion ratio (FCR), recorded in Ontario finisher barns, stratified by pig flow and used to estimate the cost of porcine reproductive and respiratory syndrome (PRRS).

| Flow type | Period | Batches | Mean | | | Minimum | | | Maximum | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | ADG (g/day) | FCR | Mort (%) | ADG (g/day) | FCR | Mort (%) | ADG (g/day) | FCR | Mort (%) |
| CF[a] | 6 months pre-outbreak | 17 | 849 | 2.81 | 4.13 | 719 | 2.54 | 1.27 | 916 | 3.24 | 12 |
| CF | 6 months post-outbreak | 14 | 802 | 2.84 | 4.7 | 590 | 2.6 | 0.79 | 896 | 3.06 | 12.86 |
| CF | 7 - 12 months post outbreak | 13 | 876 | 2.70 | 3.35 | 647 | 2.53 | 1.1 | 957 | 2.91 | 12.7 |
| AIAO[b] | 6 months pre-outbreak | 31 | 870 | 2.69 | 5.47 | 768 | 2.35 | 1.4 | 960 | 3 | 15.5 |
| AIAO | 0 - 6 months post-outbreak | 47 | 828 | 2.72 | 6.00 | 711 | 2.43 | 1.15 | 976 | 3.11 | 16.2 |
| AIAO | 7 - 12 months post-outbreak | 33 | 815 | 2.73 | 7.26 | 637 | 2.54 | 1.28 | 959 | 3.27 | 19.6 |

[a]AIAO- all-in/all/out movement of grower-finisher pigs by barn
[b]CF- continuous movement of grower-finisher pigs into and out of the barn

Table 4.3: Estimated cost of porcine reproductive and respiratory syndrome (PRRS) in Ontario over a 1-year period in nursery and finisher stages using deterministic and stochastic models

| Stage | Production parameter and time period | Deterministic mean $ | Stochastic mean $ | Stochastic (max-min)$ | |
|---|---|---|---|---|---|
| Nursery | Mortality in the first 6 months | 20,092 | 469,329 | 36,257 | 1,697,233 |
| | Mortality in the second 6 months | 35,981 | 682,514 | 8,712 | 2,641,454 |
| | Decrease in ADG[a] first 6 months | 1,056,041 | 1,902,845 | 71,063 | 7,230,747 |
| | Decrease in ADG second 6 months | 784,784 | 1,671,745 | 74,464 | 5,814,157 |
| | Increase in FCR[b] – first 6 months | 45,760 | 477,075 | 17,863 | 2,229,105 |
| | Increase in FCR – second 6 months | 16,640 | 520,433 | 14,946 | 2,335,756 |
| | Total in the first 6 months | 1,121,893 | 2,849,248 | 288,266 | 9,200,761 |
| | Total in the second 6 months | 837,405 | 2,874,692 | 472,822 | 8,497,960 |
| | Cost per nursery pig in affected systems | 4.59 | 7.05 | 3.30 | 12.27 |
| Finisher | Mortality in first 6 months | 77,292 | 703,667 | 18,605 | 3,097,763 |
| | Mortality in second 6 months | 86,184 | 836,868 | 12,727 | 3,977,751 |
| | Decrease in ADG in first 6 months | 325,440 | 1,171,876 | 45,970 | 4,575,611 |
| | Decrease in ADG second 6 months | 141,120 | 1,120,245 | 22,295 | 4,726,385 |
| | Increase in FCR – first 6 months | 555,012 | 760,737 | 23,096 | 3,185,549 |
| | Increase in FCR – second 6 months | 278,194 | 213,692 | 3,917 | 676,073 |
| | Total in the first 6 months | 957,744 | 2,636,280 | 439,297 | 8,822,529 |
| | Total in the second 6 months | 506,268 | 2,171,078 | 305,720 | 8,336,755 |
| | Cost per finisher pig in affected systems | 3.05 | 6.68 | 2.40 | 11.65 |

[a]ADG- average daily gain
[b]FCR- feed conversion ratio

# CHAPTER 5: CONCLUSION

## 5.1 Discussions, conclusions and recommendations

This study was conducted to evaluate the economic impact of PRRS outbreaks on three performance parameters related to nursery and growing-finishing production stages. Mortality, ADG and FC data were provided by six large swine production systems located in the province of Ontario. Lack of consistent and accurate records in other areas led to the decision to restrict the number of variables to be studied to these three. Unfortunately, the industry does not benefit from a standardized method of reporting production parameters. Therefore, only parameters consistently reported for the entire study population were subjects of analysis in this model.

Variables like cost of feed medication, attrition rate, veterinary expenses, with a potential to influence overall cost of disease, were left out of this study. Type of PRRS virus strain, seasonality, impact of collateral infections associated with the disease were not considered in this study but should be considered in future projects.

The results of deterministic and stochastic modeling differed in a substantial manner. This could in part be explained by two processes. First, the stochastic model was based on distributions that were defined by the minimum, maximum, and the most likely value. The minimum value in the stochastic model for each of the PRRS periods was assumed not to be lower than the baseline value for this parameter. The assumption was that PRRS cannot improve a production parameter. Therefore, the distributions were truncated. The second reason for discrepancy was the fact that maximum of the distribution was based on the most extreme cases that occurred during each of the PRRS periods. Thus, both of these factors contributed to the tendency of resulting outputs towards higher values. More work is required in order to allow more accurate incorporation of stochastic distributions into PRRS cost estimations, including accounting for correlation between production parameters.

As a novelty, this study is the first to consider type of flow as a potential factor of inference in any economical analysis conducted to determine disease impact on cost of production, in nurseries and growing-finishing barns. Thus, linked with the PRRS outbreak time variable in the model, pig flow was used to generate a more accurate estimate for the cost of impact of the outbreak.

Our values are lower than those previously published for the American swine industry. Lower feed and overhead cost in the American swine industry make this finding even more surprising. PRRS incidence rate used in the US study is higher than that considered in this Ontario study. For future reference a system of reporting outbreaks across the province and country, centralized in a main data bank will make possible real measurement of incidence rate. The recently initiated by OSHAB provincial program to control and eliminate PRRS virus from Ontario herds is a good opportunity to create a solid data base for this purpose. Surveillance protocols meant to detect outbreaks in sow herds only will eliminate confusion and establish accurate incidence rates of disease.

In the present study, the greatest contribution to the cost of a PRRS outbreak was associated with slower growth rate. This comes as a surprising finding because mortality is commonly considered the most important cause of losses in the nursery and grower stages in PRRS outbreaks. The type of virus strain and prevalence of concurrent infections may be different in the present study compared to American studies that reported higher mortality rates. The difference might also be explained by the way the cost of a dead pig is calculated between studies. In the present study dead pigs were conservatively valued as the purchase price upon entry; others have often used the lost opportunity cost if the pig had reached market weight.

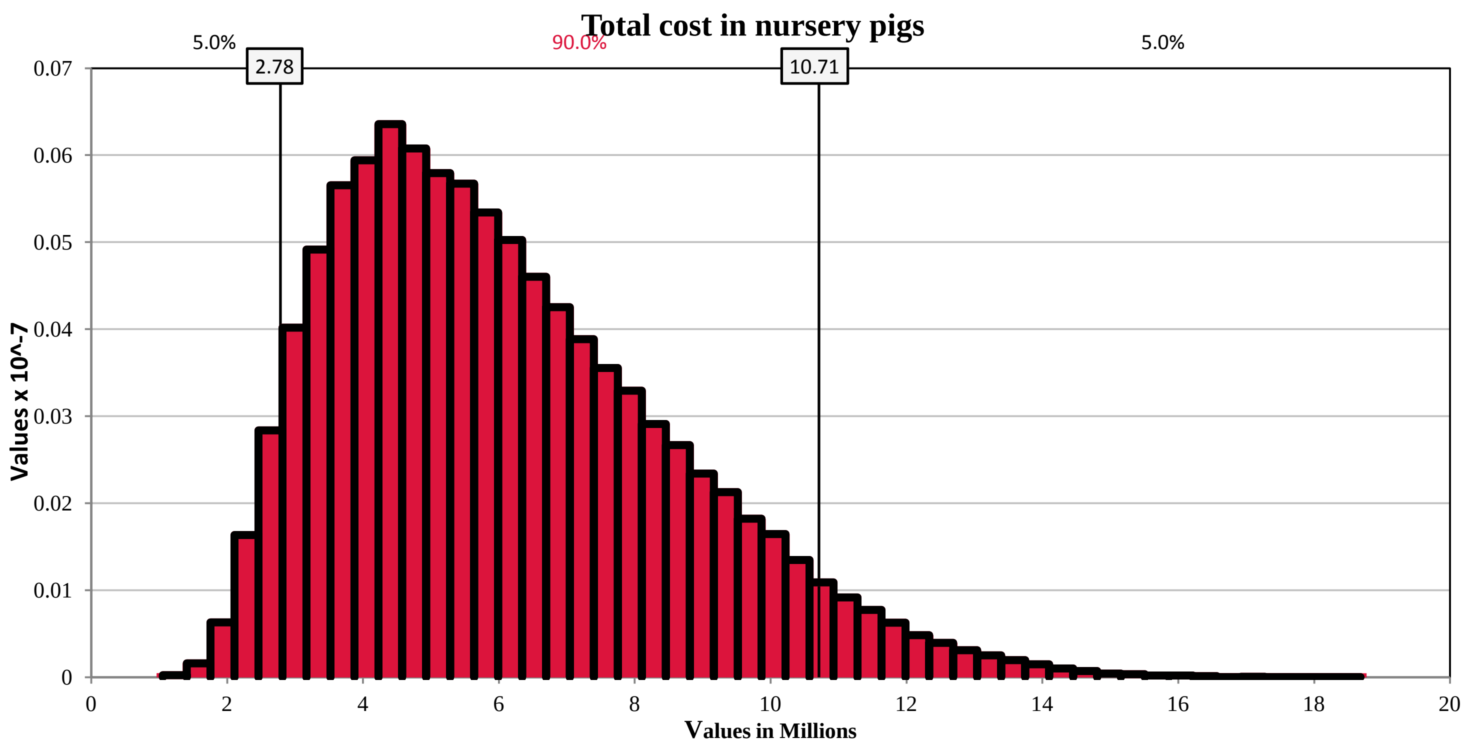
This study considered as inclusion criteria for the participant production systems to have at least one positive laboratory-confirmed diagnosis of PRRS. Time of outbreak in the sow herd was considered to be identical for time of outbreak in the nurseries and finishers in the system, which may not have been accurate.

Findings from this study could serve as reference for practitioners involved in control and elimination programs, providing recent and realistic data for Ontario swine industry. Changing type of flow during and post outbreak could mean improved recovery both economically and health wise. The performance recorded in this study suggested that AIAO flow in a nursery allows the performance in the nursery to recover within 6 months to pre-outbreak levels, but there needs to be a great deal of care and monitoring for batches leaving the nursery because AIAO systems had evidence of greater problems in the grower-finisher stage, presumably because these populations were more likely to have a large number of immunologically naive animals and very susceptible to an outbreak of disease if the virus was able to enter.

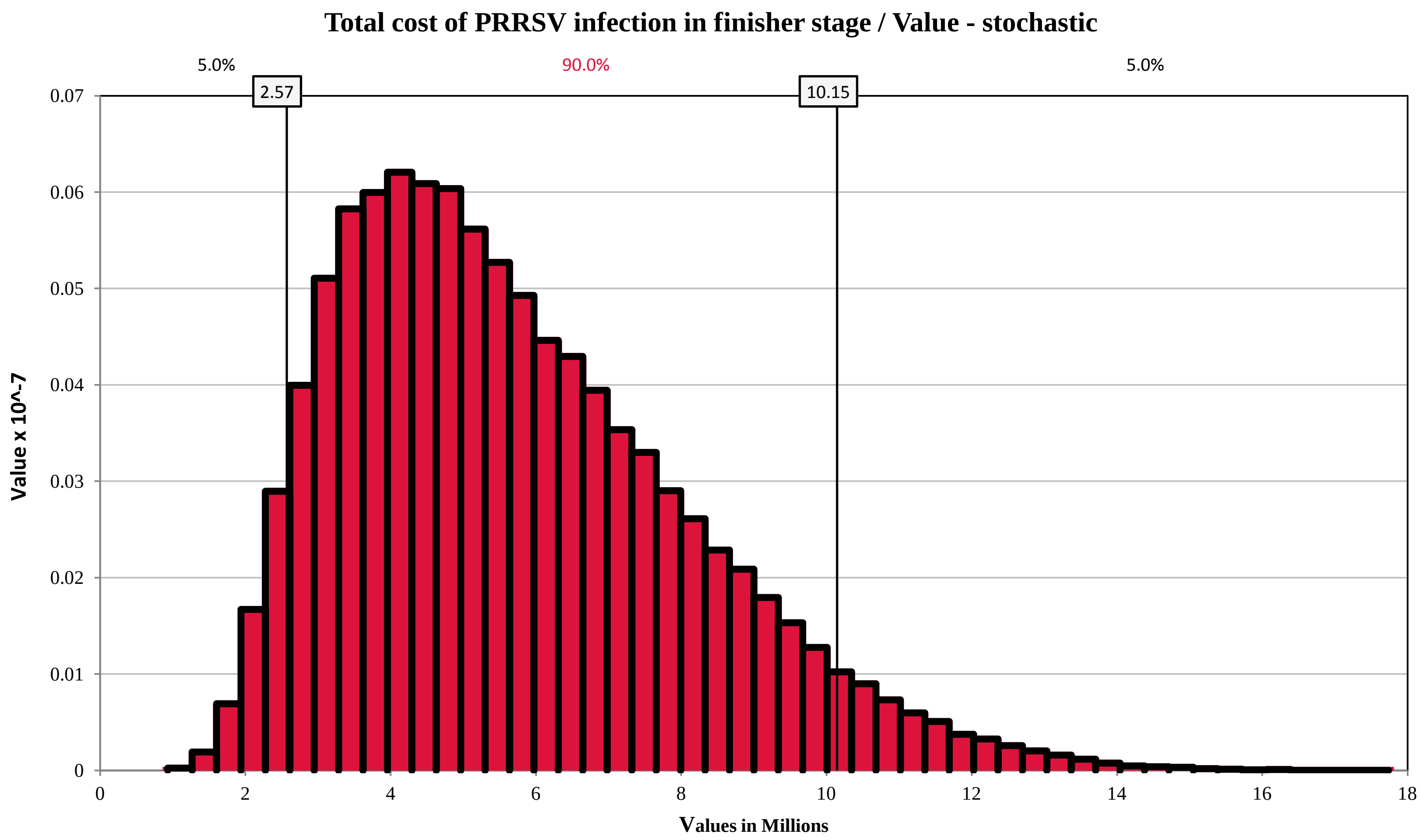
There are a number of weaknesses in the current study that need to be highlighted. The study does not consider the impact on fixed costs associated with barn ownership, with exception of the calculation for slow growth rate in the finisher phase. Other costs not taken into account include the increased costs of medication and vaccination, and costs associated with management that might be associated with a PRRS outbreak. Overall, the cost of PRRS to the Ontario industry is likely higher than the current study estimates. However it is possible that PRRS does have a positive influence on the overall price of market hogs because the disease reduces the number of pigs produced. It is difficult to factor this impact into the overall analysis.

Future studies should attempt to record additional costs associated with a PRRS outbreak including veterinary costs and the costs associated with attempts to control the disease that might include increased efforts in biosecurity and sanitation as well as disruptions in pig flow. Further refinements are also necessary to explain the huge variation in impact from herd to herd. This would include documenting the strain of virus, the immune status of the herd before the outbreak, seasonality, and other management aspects in addition to pig flow. Improvement in the methodology of estimating the impact of PRRS can be then applied to other swine diseases.

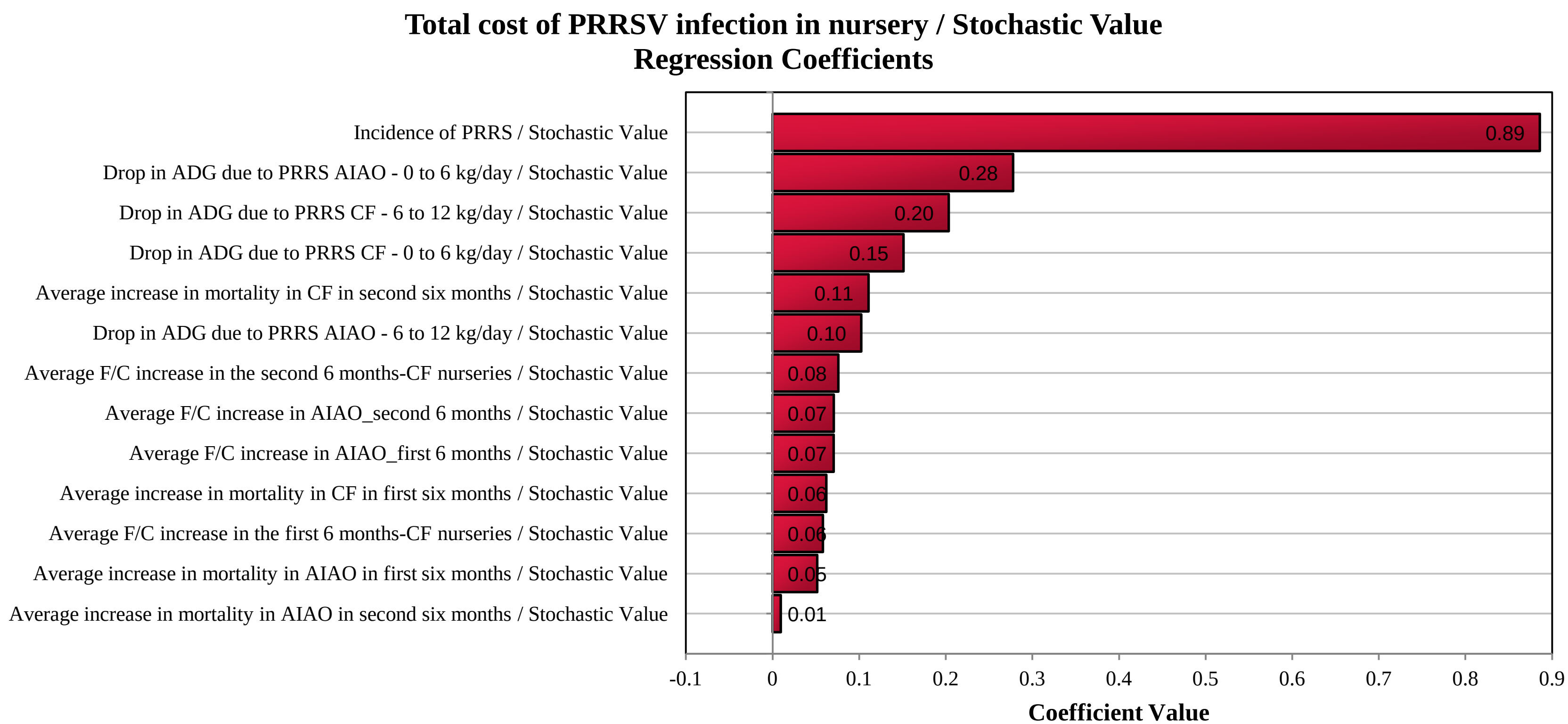
**Appendix Figure A.1: Output of cost model for nursery stage at the industry level based on stochastic simulation**



**Appendix Figure A.2: Output of cost model for finisher stage at the industry level based on stochastic simulation**

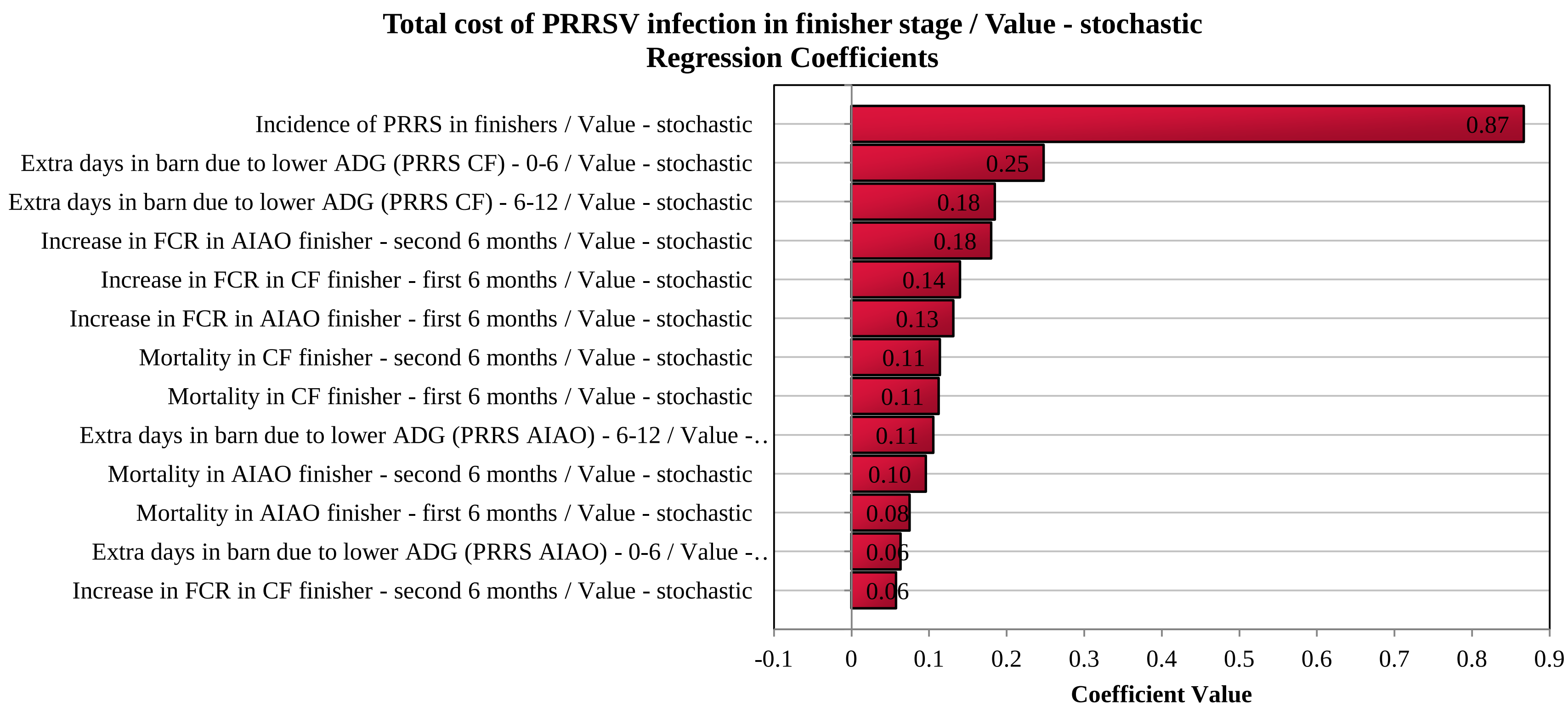


**Appendix Figure A.3: Sensitivity analysis based on the standardized regression coefficient.**




Values with higher coefficient indicate that varying the value of a parameter has more impact on the value of the outcome, which in this case is the cost of PRRS in nursery.

**Appendix Figure A.4: Sensitivity analysis based on the standardized regression coefficient.**




Values with higher coefficient indicate that varying the value of a parameter has more impact on the value of the outcome, which in this case is the cost of PRRS in the finisher sector