Transport losses in market weight pigs: II. U.S. incidence and economic impact

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ABSTRACT: An industry survey representing approximately 310 million (M) market weight pigs was conducted with 20 U.S. slaughter facilities over the calendars years of 2012 to 2015 to determine the incidence, seasonal patterns, and estimated economic impact of dead and non-ambulatory pigs. Each plant entered daily totals in a secure online database for the following variables: 1) pigs slaughtered, 2) dead on arrival (DOA; dead on the truck), 3) euthanized on arrival (EOA; non-ambulatory pig with an injury that required euthanasia), 4) dead in pen (DIP; died after unloading), and 5) non-ambulatory (pig unable to move or keep up with the rest of the group from unloading to stunning). Total dead pigs were calculated as DOA + EOA + DIP, and total losses were calculated as non-ambulatory + total dead. The economic impact was estimated based on the 4-yr weighted averages from USDA annual reports for market swine slaughtered (108,470,550 pigs), live market weight (126.9 kg), and live market price ($1.44/kg). The 4-yr weighted averages for total dead, non-ambulatory, and total losses were 0.26%, 0.63%, and 0.88%, respectively. Total dead consisted of 0.15% DOA, 0.05% EOA, and 0.05% DIP. The months with the highest rates of total dead were July (0.29%), August (0.32%), and September (0.30%), while the lowest incidence rates occurred in February (0.22%), March (0.22%), and April (0.22%). The months with the highest rates of non-ambulatory pigs were observed during the months of October (0.70%), November (0.71%), and December (0.70%), whereas the lowest rates of non-ambulatory pigs were observed during the months of April (0.57%), May (0.53%), and June (0.54%). The following assumptions were used in the economic analysis: 1) dead pigs received no value and 2) non-ambulatory pigs were discounted 30%. Based on these assumptions, the annual cost to the industry for dead and non-ambulatory pigs was estimated to be $52 M ($0.48 per pig marketed) and $37 M ($0.35 per pig marketed), respectively. Therefore, total losses represent approximately $89 M in economic losses or $0.83 per pig marketed. This is the first industry-wide survey on the incidence of transport losses in market weight pigs at U.S. slaughter facilities, and this information is important for establishing an industry baseline and benchmark for transport losses that can be used for measuring industry improvements.

Key words: fatigued, injured, mortality, non-ambulatory, swine, transport

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INTRODUCTION

Transport losses (dead and non-ambulatory pigs) in market weight pigs are a multifactorial problem that can occur from injury, fatigue, or

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death at any time from loading at the farm to stunning at the plant (Ritter et al., 2009). Several factors associated with pig transport losses include the dynamic elements of people, pigs, facility design, transportation, and environmental factors (Johnson et al., 2013; Zubrigg et al., 2017; Rioja-Lang et al., 2019). The rate of dead and non-ambulatory pigs that can result from negative outcomes relative to the aforementioned factors is an important issue to monitor and improve, as it can affect the health conditions, livelihood, and welfare of market weight pigs as they progress during the marketing process. Furthermore, dead and non-ambulatory pigs are estimated to cost the U.S. swine industry \$46 million (M) annually (Ritter et al., 2009).

Transport losses are not a new issue as published data on the percentages of dead and non-ambulatory pigs for shipments by rail and truck can be found as early as the 1930s (Smith, 1937). This topic received significant attention in the 1960s and 1970s as researchers began to study unexplained deaths in heavy muscle pigs due to Porcine Stress Syndrome (Topel et al., 1968). Over time, increased rates of dead and non-ambulatory pigs have been reported at U.S. slaughter facilities in the 1990s and 2000s (Ellis et al., 2003). However, minimal information is available on the commercial incidence of dead and non-ambulatory pigs from unloading to stunning at pork processing facilities. Globally, incidence rates for non-ambulatory pigs have only been reported from the United States (Ritter et al., 2009) and Canada (Schwartzkopf-Genswein et al., 2012).

Due to the impact that transport losses have on both animal welfare and the economics of the swine industry, many industry-wide efforts commenced in the United States to better understand the causes of transport losses and to determine management strategies that drive continuous improvements. For instance, the increased reports of dead and non-ambulatory pigs at U.S. slaughter facilities in the 1990s to 2000s (Ellis et al., 2003) drove the creation of training modules (National Pork Board's Transport Quality Assurance) and research programs aimed at reducing pre-slaughter stress and transport losses in market weight pigs. In 2004, the National Pork Board organized a workshop to bring together academic, industry, and government leaders to write a scientific literature review on transport losses in market weight pigs (Ritter et al., 2009). The objectives of the review paper were to 1) define transport losses in market weight pigs; 2) provide historical and global perspectives on transport losses; 3) explain why dead and non-ambulatory pigs represent growing animal welfare, regulatory, and economic concerns; and 4) estimate the U.S. incidence and economic impact of dead and non-ambulatory pigs. The review paper identified two key gaps in the literature on the incidence of non-ambulatory pigs: 1) national statistics for non-ambulatory pigs were not available, so field studies were used to estimate incidence and 2) the vast majority of published field studies only tracked non-ambulatory pigs to the lairage pen vs. all the way to the stunning area. Therefore, additional work is needed to confirm the non-ambulatory rates reported by Ritter et al. (2009). The objective of the present work was to conduct a multi-year industry-wide survey to estimate the incidence and economic impact of dead and non-ambulatory pigs at U.S. slaughter facilities.

MATERIALS AND METHODS

Study Design and Data Collection

An industry survey was conducted with 20 USDA-inspected pork slaughter facilities over the calendar years of 2012 to 2015 to estimate the U.S. incidence of dead and non-ambulatory pigs. The scope of data collection in this survey was limited to market hogs. Pork slaughter plants participated on a voluntary basis and each facility harvested a minimum of 5,000 pigs per day. Data were collected on 310,002,578 pigs slaughtered over the time period of January 1, 2012 to December 31, 2015, which represents 71% of the market hogs harvested over this 4-yr period (FSIS, 2013 to 2016).

A confidential and secure online database was created by Elanco Knowledge Solutions (Overland Park, KS) for data entry into the industry survey. Each processing facility was provided access to the online database via a unique user name and password. Prior to enrollment, participating processors were trained to enter data into the database using a common set of industry definitions for transport losses (Table 1). Slaughter plant employees identified and recorded daily totals for pigs slaughtered, dead on arrival (DOA), euthanized on arrival (EOA), dead in pen (DIP), and non-ambulatory. These data were entered weekly by slaughter plant employees into the confidential and secure online database. Total dead (DOA + EOA + DIP) and total losses (non-ambulatory pigs + total dead) were then calculated from entered values. Data entries were quality checked by an Elanco data analyst on a weekly basis.

Table 1. Data reported on a daily basis by participating processing facilities

Variable	Definition
Total pigs	Number of pigs slaughtered
Dead on arrival	A pig that died during the transit from the farm to the slaughter facility
Euthanized on arrival	A non-ambulatory pig with a severe injury that required euthanasia
Dead in pen	A pig that died after unloading at the slaughter facility
Non-ambulatory	A pig unable to move or keep up with the rest of the group from unloading to stunning
Total dead	Total dead = DOA + EOA + DIP
Total losses	Total losses = total dead + non-ambulatory pigs

Statistical Analysis

Weighted averages for percent DOA, EOA, DIP, non-ambulatory pigs, total dead, and total losses were calculated on a weekly basis (n = 212 weeks) for the entire 4-yr period. Statistical process control charts displaying the mean, lower critical limit, and upper critical limit were then created for each individual variable using JMP 12.1 (SAS Institute, Cary, NC). Statistical process control charts are a useful tool to evaluate and monitor process capabilities and are commonly used to assess procedures to demonstrate process control and acceptable conditions within a system (e.g., NACMCF, 2018). Therefore, these control charts were used to establish industry benchmarks for transport losses in market weight pigs and visually flag events that may be important to consider from welfare or economic standpoint. The lower and upper critical limits were set at 3 standard deviations from the mean.

Weighted averages for total dead (DOA + EOA + DIP) and non-ambulatory pigs were calculated by slaughter plant for the entire 4-yr period to calculate plant benchmark statistics. The plant means were then entered into JMP 12.1 (SAS Institute, Cary, NC), and the column rank function within JMP was used to assign plant rankings for total dead and non-ambulatory pigs. These rankings were then used to assign a plant benchmark category within total dead and non-ambulatory pigs where 1) the 5 plants with the lowest values represent the top 25%, 2) the 5 plants with the highest values represent the bottom 25%, and 3) the remaining 10 plants represent the middle 50%. Means were then calculated for each plant benchmark category (top 25%, middle 50%, and bottom 25%) by using the distribution function with JMP.

Table 2. Four-year weighted averages for transport losses in U.S. market weight pigs*

Variable	Mean†	LCL‡	UCL‖
Total dead§	0.26%	0.15%	0.37%
Dead on arrival	0.15%	0.07%	0.23%
Euthanized on arrival	0.05%	0.03%	0.07%
Dead in pen	0.05%	0.03%	0.08%
Non-ambulatory pigs¶	0.63%	0.53%	0.72%
Total losses**	0.88%	0.71%	1.05%

*Based on 310,002,578 pigs at 20 U.S. processing facilities over 212 consecutive weeks of data collection.

†Weighted average across the 20 U.S. processing facilities.

‡Lower critical limit is 3 standard deviations below the mean.

‖Upper critical limit is 3 standard deviations above the mean.

§Total dead = DOA + EOA + DIP.

¶Non-ambulatory pigs were defined as a pig unable to move or keep up with the rest of the group from unloading to stunning.

**Total losses = total dead + non-ambulatory pigs.

Weighted averages for the percent of non-ambulatory pigs, total dead, and total losses were calculated on a monthly basis (n = 48) over the entire 4-yr period to determine seasonal patterns. Data were analyzed as a one-way ANOVA using JMP 12.1 (SAS Institute, Cary, NC), where month was the fixed effect and year was the blocking factor. When the main effect of the month was significant, pairwise comparisons were conducted among months by using the Student's t-test. Significance was declared at the $P < 0.05$ level.

Economic Analysis

The economic analysis was based on the 4-yr (2012 to 2015) weighted averages for a number of market swine slaughtered (108,470,550 pigs; FSIS, 2013 to 2016), percentage of dead and non-ambulatory pigs (Table 2), average live market weight (127.0 kg; USDA-NASS, 2018), and average live market price ($1.44/kg; USDA-NASS, 2018). The economic analyses also utilized the following assumptions from Ritter et al. (2009): 1) dead pigs have zero value and 2) non-ambulatory pigs are discounted 30%. Opportunity costs for lost revenue potential were then calculated by subtracting the total price paid for dead pigs and non-ambulatory pigs from the total price paid for normal market hogs (Maes et al., 2001; Deen and Larriestra, 2004; Deen and Eggers, 2011). By using this approach, total opportunity costs to the U.S. swine industry were estimated for dead and non-ambulatory pigs and were expressed as total costs per year and costs per pig marketed.

RESULTS AND DISCUSSION

Industry Benchmarks for Transport Losses

Dead pigs. The U.S. industry averages for DOA, EOA, and DIP were 0.15%, 0.05%, and 0.05%, respectively. This suggests that there is a simple 3:1:1 ratio for DOA, EOA, and DIP, respectively. In the current study, total dead pigs averaged 0.26%. This value is in line with national statistics reported by the U.S. Food Safety Inspection Service for the years 2012 to 2015 (FSIS, 2013 to 2016; Peterson et al., 2017), which reported that total dead pigs averaged 0.21% for the same time period.

Non-ambulatory pigs. Non-ambulatory pigs are pigs unable to move or keep up with the rest of the group at the processing facility, and this may be due to injury or fatigue (Ritter et al., 2009). Unfortunately, national statistics for the U.S. incidence of non-ambulatory pigs are not available. To our knowledge, this is the first industry-wide study to report the incidence of non-ambulatory pigs at U.S. processing facilities. The industry average for non-ambulatory pigs from unloading to stunning was 0.63% (Table 2), and there was a 1:1 ratio of non-ambulatory pigs before and after the lairage pen (before lairage = 0.31%; after lairage = 0.32%). The 0.63% rate of non-ambulatory pigs found in the current study is somewhat higher than the 0.44% rate reported by Ritter et al. (2009). However, the multi-trial summary by Ritter et al. (2009) was much smaller in size than the current study (6.7 M pigs vs. 310 M pigs, respectively), and the vast majority (20 out of 23) of studies utilized in the multi-trial summary only tracked non-ambulatory pigs from unloading to the lairage pen.

With a study of this size and scale, it was not possible to classify the non-ambulatory pigs as fatigued or injured. However, previous studies have shown that the vast majority of non-ambulatory pigs seen at U.S. processing facilities display acute signs of stress (open mouth breathing, skin discoloration, muscle tremors, and/or a reluctance to move) and are classified as fatigued (Ritter et al., 2009). From a global perspective, it is interesting to note that incidence rates for non-ambulatory pigs have only been reported from the United States (Ritter et al., 2009) and Canada (Schwartzkopf-Genswein et al., 2012). It is currently unknown if non-ambulatory pigs, and in particular, fatigued pigs, are unique to North America or if non-ambulatory pigs are seen globally, but are not widely researched.

Total losses. Total transport losses (dead and non-ambulatory pigs) represented 0.88% of the 310 M pigs observed in the current study (Table 2). This value is slightly higher than the 0.69% figure reported in the multi-study analysis by Ritter et al. (2009), which as mentioned previously is likely due to considerably smaller sample size and a gap in information regarding pig ambulatory status from lairage pen to stunning.

Plant benchmark values. U.S. slaughter plant benchmark statistics for total dead pigs and non-ambulatory pigs were summarized for the top 25% (n = 5), middle 50% (n = 10), and bottom 25% (n = 5) participating slaughter plants (Table 3). The plant benchmark statistics for total dead pigs were 0.15%, 0.25%, and 0.38% for the top 25%, middle 50%, and bottom 25% of participating plants, respectively. Interestingly, a larger range in values was observed in non-ambulatory pigs across the top 25%, middle 50%, and bottom 25% of participating plants, which averaged 0.26%, 0.53%, and 1.11%, respectively. Since the scope of data collected in the current work was limited to daily totals for the number of pigs harvested, dead pigs, and non-ambulatory pigs, we can only hypothesize and speculate on why these plant differences exist. Some potential contributing factors include geographical location (Midwest vs. other locations),

Table 3. U.S. slaughter plant benchmark statistics for transport losses in market weight pigs

		Plant benchmark category[†]		
Variable	Mean[*]	Top 25%	Middle 50%	Bottom 25%
Total dead[‡]	0.26%	0.15%	0.25%	0.38%
Non-ambulatory pigs[‖]	0.63%	0.26%	0.53%	1.11%

[*]Based on 310,002,578 pigs at 20 U.S. processing facilities over 212 consecutive weeks of data collection.

[†]Percentages of total dead pigs and non-ambulatory pigs were calculated for the 4-yr period by plant. Plants were ranked in ascending order for each variable. The 5 plants with the lowest values represent the top 25%, the 5 plants with the highest values represent the bottom 25%, and the remaining 10 plants represent the middle 50%. Means were then calculated for each plant benchmark category (top 25%, middle 50%, and bottom 25%).

[‡]Total dead = DOA + EOA + DIP.

[‖]Non-ambulatory pigs were defined as a pig unable to move or keep up with the rest of the group from unloading to stunning.

plant facility design (availability of summer cooling resources at arrival [canopies, fan banks, water for showering the pigs], unloading ramp design, distance pigs are moved [from unloading to lairage pen and from lairage pen to stunning], stunning systems [electrical stunning with pigs moved single file during the final drive to stunner vs. CO_2 stunning with group handling during the final drive to the stunner]), electric prod use (during unloading and during the final drive to the stunner), transportation factors (trailer design, trailer floor space, and transport times/distances), and pig supplier factors (genetics, facility design, diet, pig health, and pig handling). Furthermore, the definition of non-ambulatory pigs includes both pigs that cannot walk and those that are slow-moving and cannot keep up with the rest of the group. Depending on how proactively plant employees and USDA inspectors interpret and implement this working definition could have a major impact on the rate of non-ambulatory pigs observed and recorded at the plant.

Statistical process control charts. As discussed above, the U.S. industry averages for dead and non-ambulatory pigs were 0.26% and 0.63%, respectively (Table 2). These values can now serve as U.S. industry benchmarks for monitoring continuous improvements in transport losses. However, these values provide very little insight into what is considered "normal" rates for dead and non-ambulatory pigs under U.S. commercial conditions. To address this question, Figures 1–3 present the statistical process control charts for weekly percentages of DOAs, EOAs, DIPs, total dead, non-ambulatory pigs, and total losses over 212 consecutive weeks at 20 U.S. processing facilities. These control charts display the mean with a lower critical limit (LCL) and upper critical limit (UCL) set at ±3 standard deviations from the mean. Values captured between the LCL and UCL reflect normal variation over multiple months and years for each category of transport losses. The UCL can be used as thresholds to alert swine producers and pork processors when their system has exceeded the upper thresholds for transport losses in market weight pigs based on historical data.

The means, LCL, and UCL for total dead, non-ambulatory pigs, and total losses are shown in tabular form (Table 2) and graphical form (Figures 1 to 3). The mean for total dead was 0.26%, and the range was 0.15% (LCL) to 0.36% (UCL). Over the 212 weeks of data collection, the UCL for total dead was exceeded 12 times with the majority of the exceptions occurring during the summer of 2014. The mean for non-ambulatory pigs was 0.63%, and the range was 0.53% (LCL) to 0.72% (UCL). Year (2014) and season (fall and winter) contributed to the majority of the values exceeding the UCL for non-ambulatory pigs. Finally, the mean for total transport losses was 0.88%, and the range was 0.71% (LCL) to 1.05% (UCL). The vast majority of values exceeding the UCL for total losses were observed during the year 2014. It is presently unclear why more values exceeded the UCL for total dead, non-ambulatory pigs, and total losses in 2014, but potential explanations include increased incidence and severity of porcine epidemic virus (Holtkamp, 2015) and increased slaughter weights (USDA-NASS, 2018). Meanwhile, total losses had several weekly values below the LCL in 2012. This was caused by low percentages of non-ambulatory pigs during the first half of the calendar year 2012, which may be attributed to the winter of 2011/2012 and spring of 2012 having some of the warmest U.S. national temperatures on record (NOAA, 2020).

Seasonal Variation in Transport Losses

Based on the control charts, seasonal patterns may exist for the incidence of dead and non-ambulatory pigs (Figures 1–3). Seasonal variation in transport losses was evaluated by testing the effects of the month on the percentage of total dead, non-ambulatory pigs, and total losses (Table 3).

Dead pigs. Seasonal variation in total dead pigs (DOA + EOA + DIP) was evaluated over the calendar years of 2012 to 2015, and the highest percentages were observed during the summer months (Table 4). More specifically, July (0.29%), August (0.32%), and September (0.30%) had higher total dead rates than January (0.23%), February (0.22%), March (0.22%), April (0.22%), November (0.24%), and December (0.24%). These trends are in line with the seasonal variation seen in the national statistics for dead market pigs reported by FSIS, where it is well documented that the percentage of dead pigs is highest during the summer months (FSIS, 2013 to 2016; Peterson et al., 2017). Therefore, swine producers, transporters, and processors need to take extra precautions during the summer months to minimize the risk of heat stress in market weight pigs. Some examples include preparing trailers for extreme weather conditions, minimizing the amount of time pigs must spend on a trailer, properly determining the fitness of pigs for transport, reducing transport loading densities, reducing stops during

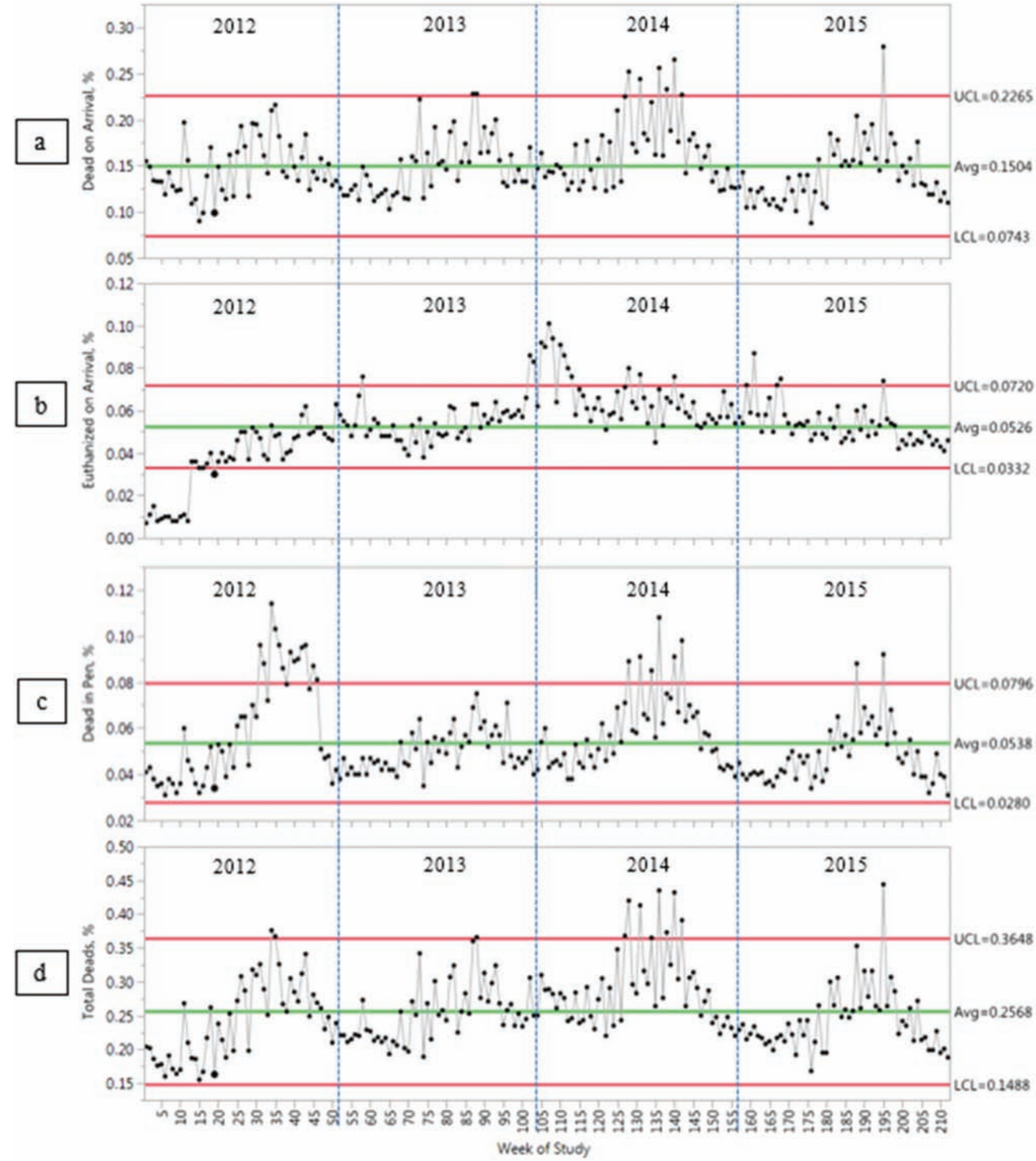

Figure 1. Statistical process control chart for the percentage of pigs identified as (a) dead on arrival, (b) euthanized on arrival, (c) dead in pens, or (d) total dead pigs at U.S. market swine processing facilities. The data was based on 310,002,578 pigs observed at 20 U.S. processing facilities over 212 consecutive weeks of data collection. Dead on arrival was defined as pigs that died during the transit from the farm to the slaughter facility. Euthanized on arrival was defined as non-ambulatory pigs with a severe injury that required euthanasia. Dead in pen was defined as pigs that died after unloading at the slaughter facility. Total dead pigs were defined as the sum of pigs that were dead on arrival, euthanized on arrival, or dead in pen. The upper critical limit (UCL) and lower critical limit (LCL) represent 3 standard deviations from the mean.

transport, and recognizing the signs of heat stress in pigs (NPB, 2017).

Non-ambulatory pigs. Seasonal variation was also observed in the percentage of non-ambulatory pigs (Table 4). The months with the highest percentage of non-ambulatory pigs occurred in the late fall and early winter months. More specifically, non-ambulatory pig rates were higher in the months of October (0.70%), November (0.71%), and December (0.70%) than in the months of February

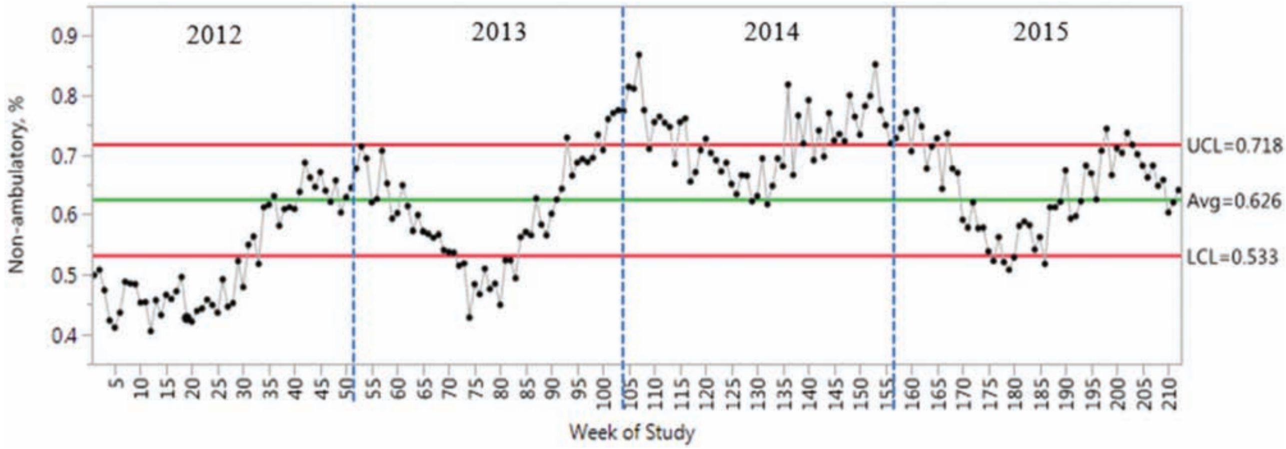

Figure 2. Statistical process control chart for the percentage of non-ambulatory pigs at U.S. market swine processing facilities. The data was based on 310,002,578 pigs observed at 20 U.S. processing facilities over 212 consecutive weeks of data collection. Non-ambulatory pigs were defined as pigs that were unable to move or keep up with the rest of the group from unloading to stunning. The upper critical limit (UCL) and lower critical limit (LCL) represent 3 standard deviations from the mean.

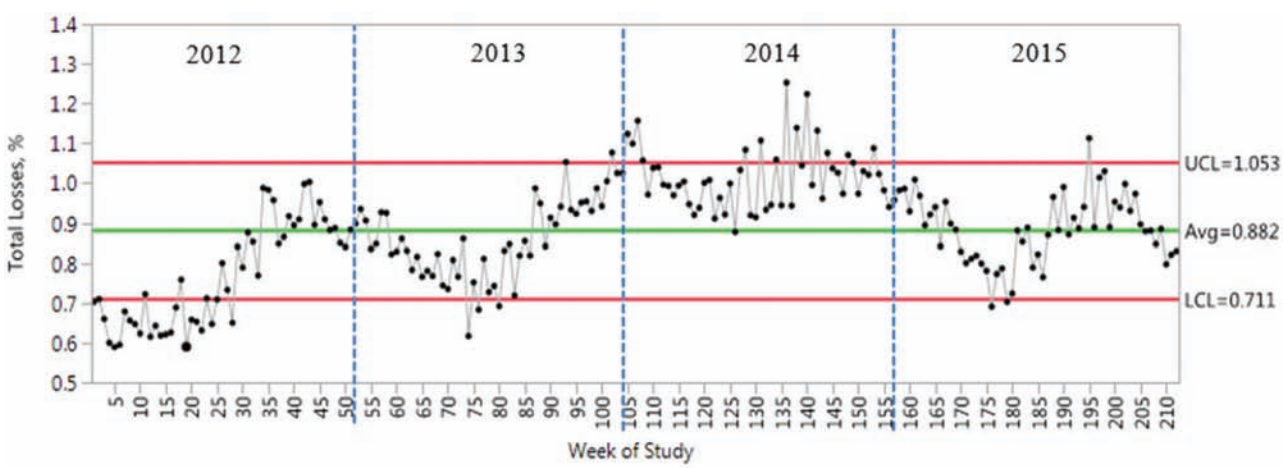

Figure 3. Statistical process control chart for the percentage of total losses at U.S. market swine processing facilities. The data was based on 310,002,578 pigs observed at 20 U.S. processing facilities over 212 consecutive weeks of data collection. Total losses were defined as the sum of total dead pigs and non-ambulatory pigs. The upper critical limit (UCL) and lower critical limit (LCL) represent 3 standard deviations from the mean.

(0.63%), March (0.59%), April (0.57%), May (0.53%), June (0.54%), July (0.58%), and August (0.63%). Field studies have also shown that the rates of non-ambulatory pigs are higher during the late fall and early winter months in the Midwestern region of the United States (Rademacher and Davies, 2005; Ellis and Ritter, 2006; Sutherland et al., 2009). Possible factors associated with the higher rates of non-ambulatory pigs in the fall and winter months include cold stress, heavier market weights, increased number of pigs moving through the marketing channel in Q4 (number of pigs harvested per quarter in the current work: Q1 = 19.4 M, Q2 = 18.4 M, Q3 = 18.6 M, and Q4 = 21.1 M), and potential changes in the health status of the pigs (Ellis and Ritter, 2006). Therefore, adjusting trailer settings (ventilation and bedding) for cold temperatures, closely monitoring slaughter weights, adjusting trailer loading densities for live weight, and quickly identifying and treating sick pigs are management strategies that may minimize the risk for late fall or early winter spikes in non-ambulatory pigs (NPB, 2017).

Total losses. When total transport losses were evaluated in the current study, there was a greater magnitude of pigs identified as non-ambulatory in comparison to DOA, EOA, or DIP across seasons. Thus, the seasonal variation of total transport losses closely followed the seasonal pattern observed in non-ambulatory pig percentages with the greatest percentages of total losses being observed during the late fall or early winter months (Table 4). More specifically, the months of September (0.96%) and October (0.97%) had higher total transport losses than the months of February (0.84%), March (0.81%), April (0.79%), May (0.79%), June (0.82%),

Table 4. Effect of month on transport losses in U.S. market weight pigs*

Month	Total deads†, %	Non-ambulatory‡, %	Total losses‖, %
January	0.23[ef]	0.66[ab]	0.88[abc]
February	0.22[f]	0.63[bcd]	0.84[cd]
March	0.22[f]	0.59[cde]	0.81[cd]
April	0.22[f]	0.57[de]	0.79[d]
May	0.26[cde]	0.53[e]	0.79[cd]
June	0.28[bc]	0.54[e]	0.82[cd]
July	0.29[abc]	0.58[cde]	0.87[bcd]
August	0.32[a]	0.63[bc]	0.96[ab]
September	0.30[ab]	0.66[ab]	0.96[a]
October	0.26[cd]	0.70[a]	0.97[a]
November	0.24[def]	0.71[a]	0.96[ab]
December	0.24[def]	0.70[a]	0.93[ab]
Pooled SEM	0.01	0.02	0.03
P-value	<0.0001	<0.0001	<0.001

[a,b,c,d,e,f]Means within a column with different superscripts differ ($P < 0.05$).

*Based on 310,002,578 pigs at 20 U.S. processing facilities over 48 consecutive months of data collection.

†Total dead = dead on arrival + euthanized on arrival + dead in pen.

‡Non-ambulatory pigs were defined as a pig unable to move or keep up with the rest of the group from unloading to stunning.

‖Total losses = total dead + non-ambulatory.

Table 5. Assumptions used for calculating the economic impact of transport losses in market weight pigs on the US pork industry for the years of 2012 to 2015

Economic assumptions	Values
U.S. market hog statistics	
Number of pigs slaughtered*	108,470,550
Average slaughter weight, kg†	127.0
Average live price paid, $/kg†	$1.44
Average market hog value, $/pig‡	$183.03
Price paid for transport losses	
Dead pigs, $/pig‖	$0.00
Non-ambulatory pigs, $/pig§	$128.12
Lost opportunity on transport losses	
Dead pigs, $/pig‖,¶	$183.03
Non-ambulatory pigs, $/pig§,¶	$54.91

*Values obtained from FSIS (2013 to 2016).

†Values obtained from USDA-National Agricultural Statistics Service (2018).

‡Average pig value = average slaughter weight × average live price paid.

‖Assumes complete loss of value on dead pigs.

§Assumes non-ambulatory pigs are discounted 30%.

¶Lost opportunity = average market hog value – price paid for dead or non-ambulatory pigs.

and July (0.87%), and this aligns with the results of other U.S. field studies (Rademacher and Davies, 2005; Ellis and Ritter, 2006).

Economic Implications

There are two different ways to evaluate the economic impact of dead and non-ambulatory pigs: 1) direct sunk production costs to the producer and 2) lost opportunity costs. Direct costs take into account all of the production costs that a swine producer has incurred to raise a weaned pig to market weight. Meanwhile, opportunity costs look at the difference in return between two different outcomes (e.g., full value market hog vs. a dead pig; and full value market hog vs. non-ambulatory pig) and quantify the lost revenue potential associated with not reaching the animal's potential (Maes et al., 2001; Deen and Larriestra, 2004; Deen and Eggers, 2011). In the case of dead and non-ambulatory pigs at the processing facility, the producer has already made all of the investments to raise a weaned pig to a full value market hog, so in theory, no additional feed costs or investments are needed to achieve the alternative outcome. Ritter et al. (2009) estimated the economic impact of dead and non-ambulatory pigs by showing the direct financial losses associated with farrow-to-finish production costs and the indirect financial losses associated with missed profit opportunities. This analysis required swine production costs and net profit per pig, which are difficult to obtain and vary greatly across swine production systems. Opportunity costs were used in the current work to quantify the economic impact of transport losses because 1) fewer input variables were needed, 2) national statistics were available from USDA for all of the input variables (e.g., market hog price paid and average market hog weight), 3) swine veterinarians have used this approach to estimate the cost of swine mortality and market culls (Deen and Larriestra, 2004; Deen and Eggers, 2011; Maes et al., 2001), and 4) quantifying lost revenue potential allows producers to compare the cost of implementing new pig handling/transportation interventions (e.g., changes in facility design and transport loading density) vs. the revenue potential for the expected improvements in dead and non-ambulatory pigs.

Opportunity costs for dead and non-ambulatory pigs at U.S. swine processing facilities were calculated for the calendar years of 2012 to 2015 by using national statistics (FSIS, 2013 to 2016; USDA-NASS, 2018). The average value of a market hog for the years of 2012 to 2015 in the United States was $183.03 (Table 5) and the

Table 6. Economic impact of transport losses in market weight pigs on the U.S. pork industry for the years of 2012 to 2015

	Transport losses		Lost opportunity		
	Pigs, %*	Pigs, No.†	Cost, $/loss‡	Total costs, $‖	Cost per pig marketed, $†,$
Dead pigs	0.26%	278,769	$183.03	$51,023,263	$0.47
Non-ambulatory pigs	0.63%	679,026	$54.91	$37,284,703	$0.34
Totals/averages	0.88%	957,795	$92.20	$88,307,966	$0.81

*Values for dead and non-ambulatory pigs were obtained from Table 2.

†Values are based on 108,470,550 pigs slaughtered annually and were obtained from Table 4.

‡Values for opportunity costs were obtained from Table 4.

‖Total opportunity costs = opportunity cost per loss × number of losses.

$Cost per pig marketed = total opportunity costs/total pigs marketed.

following assumptions were used for transport losses: 1) dead pigs had a complete loss of value and 2) non-ambulatory pigs were discounted 30% (Ritter et al., 2009). Therefore, instead of receiving full market value ($183.03), producers received $0 for a dead pig and $128.12 for non-ambulatory pigs after the 30% discount was applied. The opportunity cost calculations were then used to quantify the difference between the total payment received for dead and non-ambulatory pigs vs. the alternative outcome of full market value. The lost opportunity values for dead and non-ambulatory pigs were $183.03 and $54.91 per pig, respectively (Table 5). These opportunity values were then applied to the U.S. swine industry on an annual basis for the years of 2012 to 2015 (Table 6) by using the following assumptions: 1) 108,470,550 pigs were slaughtered annually, 2) the U.S. industry average for total dead pigs was 0.26%, and 3) the U.S. industry average for non-ambulatory pigs was 0.63%. This information was used to estimate the total number of dead and non-ambulatory pigs per year, and these numbers were then multiplied by the lost opportunity values for dead ($183.03) and non-ambulatory pigs ($54.91). Lost opportunity costs were expressed as total costs to the U.S. swine industry and cost per pig marketed. The lost opportunity for transport losses in market weight pigs from 2012 to 2015 was estimated to be $88 M (dead pigs = $51 M; non-ambulatory pigs = $37 M), and this was translated to a lost opportunity cost of $0.81 per pig marketed (dead pigs = $0.47 per pig marketed; non-ambulatory pigs = $0.34 per pig marketed). These estimates are higher than the $46 M estimated by Ritter et al. (2009), but the differences are likely due to the current work using higher rates of dead (0.26% vs. 0.22%, respectively) and non-ambulatory pigs (0.63% vs. 0.44%, respectively), larger numbers of pigs harvested per year (108 M vs. 104 M, respectively), heavier slaughter weights (127 kg vs. 122 kg, respectively), and higher market prices ($1.44/kg vs. $1.03/kg, respectively).

IMPLICATIONS

This industry-wide survey represents 310 M market hogs and approximately 71% of the U.S. market hogs slaughtered over the calendar years of 2012 to 2015. It is the first study of this size and scale to quantify the U.S. commercial incidence of dead and non-ambulatory pigs from unloading to stunning at pork processing facilities. The current work now sets the U.S. industry benchmarks for dead and non-ambulatory pigs at 0.26% and 0.63%, respectively. Furthermore, this study confirmed that the rate of dead pigs increased during the summer months, while non-ambulatory pig rates increased during the late fall or early winter months. By defining the incidence rates, seasonal variation, and economic impact of dead and non-ambulatory pigs, U.S. swine producers now have more information necessary to measure and monitor continuous improvements for animal welfare in the U.S. swine industry. The next step is for researchers and the U.S. swine industry to identify and implement management strategies that minimize the seasonal variation in dead and non-ambulatory pigs. For example, optimal trailer settings (ventilation openings, internal showering systems, and use of bedding) and loading densities (kg/m^2) vary across seasons and can serve as management strategies to reduce seasonal variation in dead and non-ambulatory pigs (reviewed by Rioja-Lang et al., 2019).

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LITERATURE CITED

Deen, J. and K. Eggers. 2011. Estimates of opportunity costs associated with mortality and inadequate growth rates in the US. Proceedings of the 2011 American Association of Swine Veterinarians; Phoenix (AZ); p. 387–388– [accessed July 12, 2018]. https://www.aasv.org/library/swineinfo/series_index.php?id=4#86.

Deen, J. and A. Larriestra. 2004. Lost income in grow/finish: the problem of lightweight, cull, and dead pigs. Proceedings of the 2004 Manitoba Swine Seminar. [accessed July 13, 2018]. http://www.prairieswine.com/lost-income-in-grow-finish-the-problem-of-lightweight-cull-and-dead-pigs/.

Ellis, M., F. McKeith, D. Hamilton, T. Bertol, and M. Ritter. 2003. Analysis of the current situation: what do downers cost the industry and what can we do about it? Proceedings of the 4th American Meat Science Association Pork Quality Symposium; Columbia (MO); p. 1–3.

Ellis, M., and M. Ritter. 2006. Impact of season on production: transport losses. Proceedings of the 2006 Allen D. Leman Swine Conference; St. Paul (MN); p. 205–207.– [accessed July 12, 2018]. https://conservancy.umn.edu/handle/11299/142088.

FSIS. 2013. Market swine condemned ante-mortem for deads in USDA inspected plants for the calendar year of 2012. FOIA Case #2013–100. Food Safety Inspection Service, Washington, DC.

FSIS. 2014. Market swine condemned ante-mortem for deads in USDA inspected plants for the calendar year of 2013. FOIA Case #2014–200. Food Safety Inspection Service, Washington, DC.

FSIS. 2015. Market swine condemned ante-mortem for deads in USDA inspected plants for the calendar year of 2014. FOIA Case #2015–188. Food Safety Inspection Service, Washington, DC.

FSIS. 2016. Market swine condemned ante-mortem for deads in USDA inspected plants for the calendar year of 2015. FOIA Case #2016–113. Food Safety Inspection Service, Washington, DC.

Holtkamp, D. 2015. PEDv in the US: overview, history, lessons. Proceedings of the 3rd International Biosafety & Biocontainment Symposium: Bio-risk Management in a One Health World; Baltimore (MD); [accessed July 12, 2018]. https://arssymposium.absa.org/wp-content/uploads/2015/02/1000_Holtkamp_ARS_USDAFeb4_2015.pdf.

Johnson, A. K., L. M. Gesing, M. Ellis, J. J. McGlone, E. Berg, S. M. Lonergan, R. Fitzgerald, L. A. Karriker, A. Ramirez, K. J. Stalder, et al. 2013. 2011 and 2012 Early Careers Achievement Awards: farm and pig factors touching welfare during the marketing process. J. Anim. Sci. 91:2481–2491. doi:10.2527/jas.2012-6114.

Maes, D., A. Larriestra, J. Deen, and R. Morrison. 2001. A retrospective study of mortality in grow-finish pigs in a multi-site production system. J. Swine Health Prod. 9(6):267–273.

NACMCF. 2018. Response to questions posed by the Department of Defense regarding microbiological criteria as indicators of process control or insanitary conditions. National Advisory Committee on Microbiological Criteria for Foods; U.S. Department of Agriculture; Food Safety and Inspection Service; Office of Public Health Science. J. Food Prot. 81(1):115–141. doi:10.4315/0362-028X.JFP-17–294.

NOAA. 2020. U.S. state of climate and national weather summary information for the calendar year of 2012. National Centers for Environmental Information – National Oceanic and Atmospheric Administration, Asheville, NC; [accessed March 23, 2020]. https://www.ncdc.noaa.gov/sotc/summary-info/national/201212.

NPB. 2017. Transport quality assurance – version 6 handbook. National Pork Board, Des Moines, IA; [accessed July 12, 2018]. https://d3fns0a45gcg1a.cloudfront.net/sites/all/files/documents/TQA/2017-Version6/TQA.V6_Handbook.pdf.

Peterson, E., M. Remmenga, A. D. Hagerman, and J. E. Akkina. 2017. Use of temperature, humidity, and slaughter condemnation data to predict increases in transport losses in three classes of swine and resulting foregone revenue. Front. Vet. Sci. 4:67. doi:10.3389/fvets.2017.00067.

Rademacher, C. and P. Davies. 2005. Factors associated with the incidence of mortality during transport of market hogs. Proceedings of the Allen D. Leman Swine Conference; St. Paul (MN); p. 186–191.– [accessed July 12, 2018]. https://conservancy.umn.edu/bitstream/handle/11299/143561/Rademacher.pdf;sequence=1.

Rioja-Lang, F. C., J. A. Brown, E. J. Brockhoff, and L. Faucitano. 2019. A review of swine transportation research on priority welfare issues: a Canadian perspective. Front. Vet. Sci. 6:36. doi:10.3389/fvets.2019.00036.

Ritter, M. J., M. Ellis, N. L. Berry, S. E. Curtis, L. Anil, M. Benjamin, D. Butler, C. Dewey, B. Driessen, P. DuBois, et al. 2009. Transport losses in market weight pigs: I. A review of definitions, incidence and economic impact. Prof. Anim. Sci. 25:404–414. doi:10.15232/S1080-7446(15)30735-X.

Schwartzkopf-Genswein, K. S., L. Faucitano, S. Dadgar, P. Shand, L. A. González, and T. G. Crowe. 2012. Road transport of cattle, swine and poultry in North America and its impact on animal welfare, carcass and meat quality: a review. Meat Sci. 92:227–243. doi:10.1016/j.meatsci.2012.04.010.

Smith, W. W. 1937. Pork production. Marketing; market classes and grades. 1st rev. ed. The MacMillan Company, New York, NY. p. 446–468.

Sutherland, M. A., A. McDonald, and J. J. McGlone. 2009. Effects of variations in the environment, length of journey and type of trailer on the mortality and morbidity of pigs being transported to slaughter. Vet. Rec. 165:13–18. doi:10.1136/vetrec.165.1.13.

Topel, D. G., E. J. Bicknell, K. S. Preston, L. L. Christian, and C. Y. Matsushima. 1968. Porcine stress syndrome. Mod. Vet. Pract. 49:40–41 and 59–60.

USDA-NASS. 2018. Quick stats—U.S. market hog slaughter statistics. United States Department of Agriculture, National Agricultural Statistics Service; [accessed May 23, 2018]. https://quickstats.nass.usda.gov/results/03AB849D-DAB1-304A-A209-6A2A90FB4A39?pivot=short_desc.

Zurbrigg, K., T. van Dreumel, M. Rothschild, D. Alves, R. Friendship, and T. O'Sullivan. 2017. Pig-level risk factors for in-transit losses in swine: a review. Can. J. Anim. Sci. 97:339–346. doi:10.1139/cjas-2016-0193.