Environmental Quality and Animal Welfare Implications of Commercial Livestock Transportation to Slaughter Facilities in North America: A Review

by

Sarah Jane Schuetze

B.S., Kansas State University, 2017

A Report

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Biological and Agricultural Engineering
College of Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2017

Approved by:

Major Professor
Dr. Ronaldo Maghirang

Copyright

Abstract

There are several stressful events throughout an animal's lifetime, but transportation is considered one of the most detrimental events to animal welfare by many professionals, regardless of species. Transportation consists of several different interacting and compounding factors that can affect animal welfare and meat product quality. The purpose of this report is to review current industry practices of land transport of different livestock types to slaughter facilities, primarily within the United States and Canada. This review evaluated species-specific transport practices and subsequent effects on animal welfare and carcass quality for both animal welfare and economic outlooks.

Regulations are placed on the driver and time limits that the animals are allowed to be in transit. Trailer style use partially depends on the age and species of animal that is being hauled. Cattle are more likely to be hauled in pot belly trailers, while pigs are often transported in either pot belly or straight deck trailers. Poultry trailer type directly depends on the age of the birds being transported. Enclosed trailers are more often used in the European Union but are slowly making an impression on United States and Canadian markets.

Cattle are transported several times in their lives with each trip varying in duration, loading density, and other environment altering factors. Each time the animals are transported there is the risk of low air flow, heat, or cold stress that can reduce animal welfare. Loading density has been broken down to equations, duration is limited by hours in trailer and location, and changes in physiology and behavior further exacerbate cattle transport stress.

Pigs are transported fewer times than cattle, but thousands of pigs die during this process each year. Market weight pig mortality predictability increases with increasing temperature-humidity index and also increasing loading densities, with a specific equation to quantify this

correlation. Shrink is another factor that can be linearly derived as transport time increases in swine. Fatigued Pig Syndrome is welfare issues that can impact the meat product resulting in pale, soft, and exudative pork.

Poultry are usually only shipped once or twice and require special trailers and equipment. Shipping crates or modular drawers are used for grown birds where the birds are loaded into these containers, and then placed on a poultry trailer. Poultry have a very narrow comfort window of 21°C to 24°C, making transport difficult and detrimental to their welfare. Loading density is based on type and size of shipping container; however, regardless of loading density, the likelihood of bird death increases drastically as duration increases.

Table of Contents

List of Figures

List of Tables

Abbreviations

bpm – beats per minute

BW – body weight

D&D – Down and Dead

DFD – Dark, Firm, and Dry

DOA – Dead on Arrival

ELD – Electronic Logging Device

FCS – Fatigued Cattle Syndrome

FPS – Fatigued Pig Syndrome

g/s – gram per second

kg – kilogram

kg/m^2 – kilogram per square meter

m/s – meter per second

m^2 – square meter

PSE – Pale, Soft, and Exudative

TCZ – Thermal Comfort Zone

THI – Temperature-Humidity Index

TNZ – Thermal Neutral Zone

U – Velocity

W – Watt (Joule per second)

Acknowledgements

I acknowledge, with gratitude, the support and encouragement from my committee members. Dr. Maghirang has been an excellent source of guidance and motivation throughout my undergraduate and graduate degrees. His patience and mentorship have helped me flourish and his shared knowledge will never be forgotten. I appreciate Dr. Thomson and the invaluable industry exposure I received under his direction. These experiences shaped me as an individual and as a researcher, and will be something I carry with me into future industrial opportunities. Dr. Liu is always willing to help and encourages deeper thought processes, regardless of the topic, for which I am very incredibly grateful.

I wish to thank the Biological and Agricultural Engineering Department. There are so many individuals who were always available with encouragement and advice. This has been my niche and my home away from home for over half a decade and it has become a part of who I am. I would also like to thank the College of Veterinary Medicine for allowing me to become an adopted member for the past few years while completing my graduate experience.

I would like to thank my sister, Rachel, who has supported me through everything. I am forever grateful to my mother, Carol, for her endless encouragement and my father, Chris, who was never too busy to be my sounding board. In addition, I would like thank Tyler for making me put things in perspective. Also, a huge “Thank you” to all my family, friends, peers, and professors who have encouraged me to stay focused as I completed this graduate experience.

Chapter 1 - Introduction

Transportation is considered one of the most stressful events that animals must endure during their lifetime (Grandin, 2001; Kettlewell et al., 2005). The overall transportation process includes gathering and holding livestock before loading, the time it takes to move and load the animals, time spent within the trailer (stationary and moving), waiting on the truck to unload at destination, and finally the unloading process (Tarrant and Grandin, 2000). This process has several aspects that contribute to the stress to the animal and some researchers have found that the effects of stress vary according to the actual stressor as well as the magnitude and frequency of the source of stress (Marahrens et al., 2011).

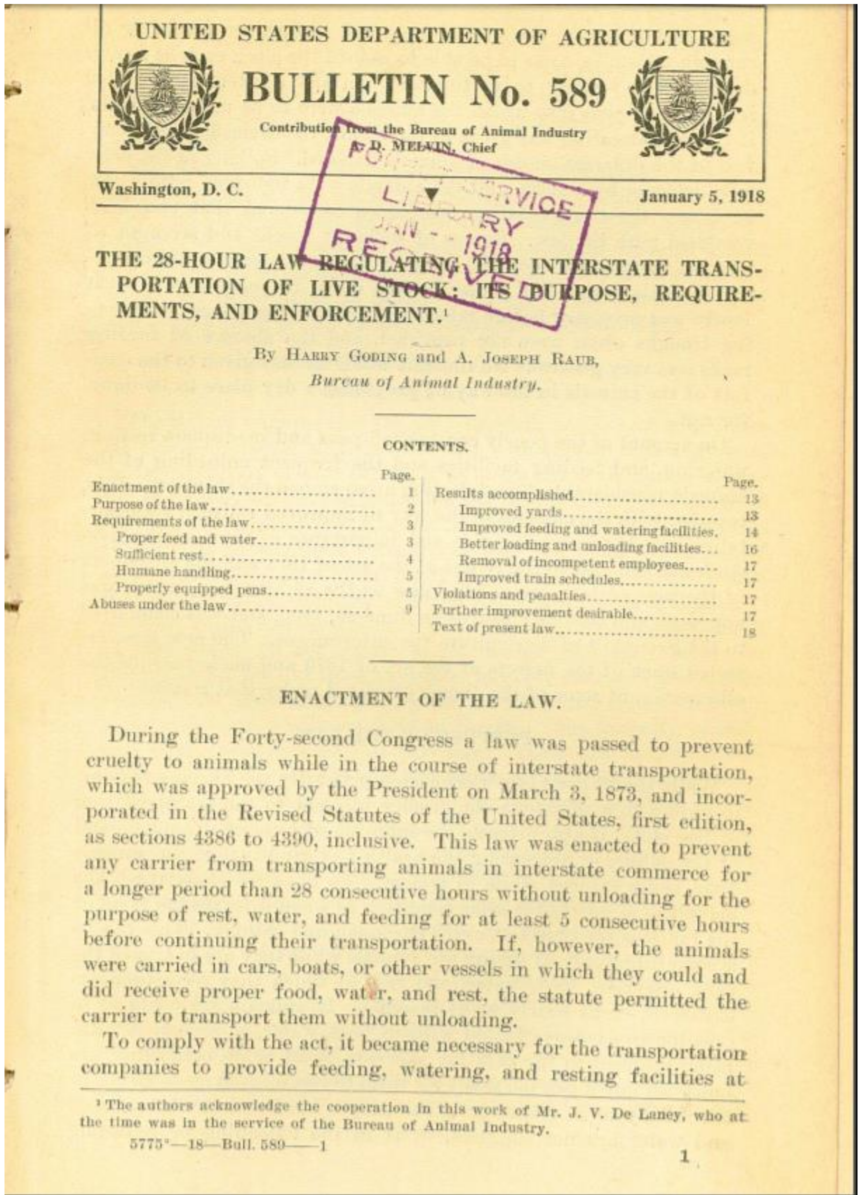
1.1 Transportation Regulations

Each country makes their own regulations regarding livestock transport and some regulations, such as weight limits, can even vary by state or region. The United States uses a 28-hour transport limit (USDA, 1994) which is one of the shortest time allowances of all countries. Canada allows the animals to be in transport for 48 hours unless the destination can be reached within 52 hours in which case the truck can proceed to its final destination (CARC, 2001), and the European Union caps transport time to 30 hours (EU, 2005). Each of these time constraints cannot be exceeded before the animals must be offloaded and allowed access to food and water for a minimum amount of time (usually 5 hours) before being allowed to recommence their journey (Schwartzkopf-Genswein et al., 2012). It must be noted that the drivers have driving hour limitations that can affect the length of the animal's journey.

Currently, truck drivers are allowed to be actively driving for 11 hours in a 14-hour period (driving window), where fuel, rest stops, weight station check in, loading, unloading, etc.

can make up the additional 3 hours, before they are required to completely shut down and be off duty for 10 consecutive hours (FMCSA, 2017a). These regulations will be further enforced when a new regulation is enacted requiring electronic logging devices (ELDs), also known as “engine timers” where engine hours will be electronically recorded to ensure that the already established working hours are obeyed to a more precise limit. There are several groups that are trying to add an animal-based agricultural exception to this law to ensure that animals are transported safely to the destination as quickly as possible. However, currently base exemption for this change only applies to loads that originate within 150 air miles (actual distance, not driving distance) from the destination, thus excluding long haul loads even those animal welfare is more critical in long than short hauls in many scenarios (FMCSA, 2017b).

The 28-hour transport law in the United States was first presented as a guideline for the transport of animals by train in 1873 and was established as federal regulation for the interstate transport of livestock by the USDA in 1918 (Figure 1; Goding and Raub, 1918).



UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 589

Contribution from the Bureau of Animal Industry
A. D. MELVIN, Chief

Washington, D. C. January 5, 1918

THE 28-HOUR LAW REGULATING THE INTERSTATE TRANSPORTATION OF LIVE STOCK; ITS PURPOSE, REQUIREMENTS, AND ENFORCEMENT.[1]

By HARRY GODING and A. JOSEPH RAUB,
Bureau of Animal Industry.

CONTENTS.

ENACTMENT OF THE LAW.

During the Forty-second Congress a law was passed to prevent cruelty to animals while in the course of interstate transportation, which was approved by the President on March 3, 1873, and incorporated in the Revised Statutes of the United States, first edition, as sections 4386 to 4390, inclusive. This law was enacted to prevent any carrier from transporting animals in interstate commerce for a longer period than 28 consecutive hours without unloading for the purpose of rest, water, and feeding for at least 5 consecutive hours before continuing their transportation. If, however, the animals were carried in cars, boats, or other vessels in which they could and did receive proper food, water, and rest, the statute permitted the carrier to transport them without unloading.

To comply with the act, it became necessary for the transportation companies to provide feeding, watering, and resting facilities at

[1] The authors acknowledge the cooperation in this work of Mr. J. V. De Laney, who at the time was in the service of the Bureau of Animal Industry.

5775°—18—Bull. 589——1

1

Figure 1. Scan of original 28-hour law regulation bulletin (Goding and Raub, 1918).

Slight modifications have been made over time which included altering the civil penalties, mainly by the inclusion of fines, ranging from $100 to $500 for each offense, which were put into effect in 1994, but otherwise the law has remained relatively unchanged (USDA, 1994). Slow regulation changes and the improvements made within European Union transportation systems have brought into question animal welfare concerns within the United

States and Canada but increasing restrictions on driver time allowances and practices can result in animals being on the truck for extended periods of time. Currently, some trucking companies will have two drivers ride together so when one driver clocks out, the other can continue the journey so as to not delay the cattle and keep them in transit longer than necessary (Crum and Morrow, 2002). This practice might become more common as a way to ensure the animals reach their destination before the ELDs clock the driver out. This will depend on how the regulations are worded, somehow the two drivers must be able to operate with the same engine and have two separate log books which could be a potential issue since ELDs record engine hours only. Regardless of means, the results of transportation should be a balance of profitability and welfare of the animal during transport (European Commission, 2001; CEC, 2005). The infiltration of European designs shows there could be grounds for the United States and Canada to reevaluate welfare concerns in transport, while still maintaining economic feasibility.

The North American Meat Institute (NAMI) Foundation emphasizes the importance of reducing the amount of time spent waiting to unload livestock at slaughter facilities and urges facilities to place higher importance on scheduling truck arrival, which would allow a steady flow of trailers and decrease wait times (Grandin, 2012). Facilities must have a continuous influx of animals to process to achieve maximum profitability, but limited lairage space results in animals often waiting on trucks for long periods of time after transit before being offloaded. Dewey et al. (2004) and Pilcher et al. (2011) reported that a large portion of finished hog losses occurred during the stationary period at the slaughter facility. In an effort to reduce the waiting periods the Animal Handling Audit (Grandin, 2010) gave scores to animal processing facilites during their audits which consisted of full points for trucks that sat waiting at slaughter facilities for an hour or less before unloading, and started docking points for each additional 30 minutes of wait time after the initial hour, but there were no regulation changes on scheduling and arrival times which would cause the extended wait times.

1.2 Objectives

The objectives of this report are to review current industry practices of land transport of animals to slaughter facilities, and identify industry research and development needs

1.3 Organization of Report

The report first describes different commercial trailer designs currently used in industry (Chapter 2). These designs include pot belly, straight deck, poultry, and enclosed trailer designs. Each trailer type features a computer generated internal schematic and/or picture of the trailer as well as descriptions an information regarding animal transport logistics.

After the trailer designs are addressed, the report is organized by species. The species selected for this report are cattle (Chapter 3), swine (Chapter 4), and poultry (Chapter 5) for they make up the largest portions of meat production within the United States and Canada. Each species section evaluates the microclimate, loading density, duration, and animal behavior impacts on animal welfare and subsequent carcass quality. Each section also includes research or development suggestions to further understand the effects of transport upon that species.

Chapter 2 - Trailer Designs

Commercial livestock trailers have had distinct styles with very few major modifications over the last 50 years (Merritt Equipment Co., 2017; Wilson Trailer, 2017a). These trailers are hauled by semi-trucks (tractor trailer) vehicles which means there must be a set of standards that match the trucks to the trailers. All trailers have a maximum height of 4.1 m (13.5 ft) in order to fit under standard traffic lights and overpasses and can only be 2.6 m (8.5 ft) wide to fit standard width requirements on highways unless alternative measures are taken and driving requirements are met. Lengths tend to vary from 14.6 m to 16.2 m (48 ft to 53 ft) but can be customized depending on the company and individual needs. Some regions, like the EU, consider the overall length of the truck and trailer whereas others, like the United States and Canada, regulate only the trailer. Areas that take the truck length into account often use “cabover trucks” for the cab of the truck sits over the engine block instead of having the engine in front of the truck, reducing the amount of length taken up by the truck and allowing for longer loads to be hauled.

A point of contention within countries is internal trailer airflow. The airflow in commercial livestock trailers is due to passive ventilation that is driven by internal air buoyancy and pressure gradients around the trailer. As the vehicle moves, air is split to either side of the trailer by the front of the truck, travels past the nose (the front of the trailer close to where the trailer connects to the truck), and reattaches to the sides of the trailer towards the rear (Muirhead, 1983; Mitchell and Kettlewell, 2008). This results in a zone of strong negative pressure near the nose of the trailer and a lesser zone at the rear, meaning that inlets and air uptake happens in the back end of the trailer, moves up the length of the trailer over the backs of the animals, and exits through outlets in the nose (Ellis et al., 2010; Gilkeson et al., 2016).

Figure 2 is a simulation that shows that there are many areas within the trailer that have little to no airflow (dark blue). The nose of the trailer is located at the left of the image and the back of the trailer is on the right, showing that air is taken in at the back of the trailer and moves towards the front. There is some airflow around the simulated animals (grey drop shapes) towards the front of the trailer but there is more air flow up located in the back region of the trailer and also for the majority of the midline of the trailer. Muirhead (1983) found similar results in full size commercial pot belly trailers with simulated cattle.

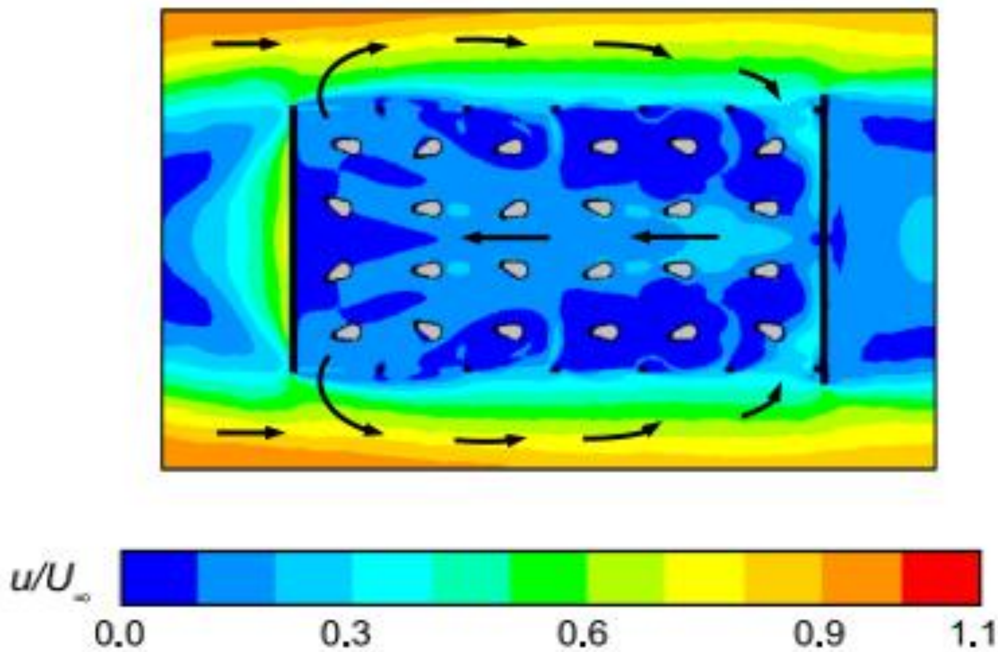


Figure 2. Aerial view of relative velocity of a small livestock trailer moving to the left at a velocity of U=13.41 m/s (Gilkeson et al., 2016).

The trailers in these two studies were passively ventilated with openings that run the length of the trailer. Both pot belly and straight deck trailers utilize this ventilation style but different hole sizes, designs, and configurations can be set either by the manufacturer or special ordered by the buyer.

(a) (b) (c)

Figure 3. Opening configurations: (a) punch hole, (b) duffy, and (c) slat.

The term "punch hole" is a blanket term used to describe all holes seen on Figures 3a and 3b. Technically, the largest hole at the top in Figures 3a and 3b is called an arm hole so that truck drivers may insert arm, sorting stick, or prod to encourage the movement of animals without entering the trailer. The smaller, circular holes seen on Figure 3a, are called punch holes. There are a variety of trailer manufacturers that utilize this style in their trailers. Figure 3b is of a Wilson trailer that has a specific patent on the oval holes that are named duffys and are the only company that uses this design, making the oval holes their trademark (Wilson Trailer, 2017a).

Figure 3c shows a slat design. This design is seen more often in straight deck trailers rather than pot belly trailers and can be designed so there is a sliding component behind them to allow for internal “boarding” without having to place actual boards across the openings. These three designs can be viewed on both commercial and small livestock trailers in a variety of configurations.

Punch hole and slat configuration is one of many modifications that have been made in an attempt to alter or enhance the airflow in certain types of trailers but these efforts tend to be more species driven in the United States and Canada and are thus, developing slower than in places like the European Union where such modifications are becoming requirements.

Clearance and air flow alterations are not uncommon but vibration and lack of shock support have been deemed as a universal problem in livestock trailers and are not often addressed. Part of the problem is due to drivers often overinflating tires to extend the life of the tire. Consequently, it will cause an increase in the vibration in the trailer, which could lead to increased stress on the cattle (Stevens and Camp, 1979; Grandin, 2014). Vibration causes stress through muscle fatigue and also displaces the animal’s center of gravity making slips and falls more frequent especially during turning and breaking (Bulitta, 2015). In addition, standing orientation and road conditions could exacerbate these factors (Hall and Bradshaw, 1998; Magdesian and Smith, 2002; Gebresenbet et al., 2011; Santurtun and Phillips, 2015).

2.1 Pot Belly Trailers

Pot belly cattle trailers, also known as feeder/fat trailers or feeder wagons, are distinct from the outside (Figure 4). The term “pot belly” comes from the lowest level of the trailer or the drop-down belly that starts after the front axle of the trailer and drops down to approximately

0.5m (1.5ft) above the ground, and then lifts back up just before the back axle, giving the trailer a “belly” and allowing for better space utilization. This design is very similar to drop deck trailers and gives better stability for this style has a much lower center of gravity than a straight deck trailer that sits completely above the axles.

Figure 4. Pot belly trailer with rear tri-axle (Wilson Trailer, 2017b).

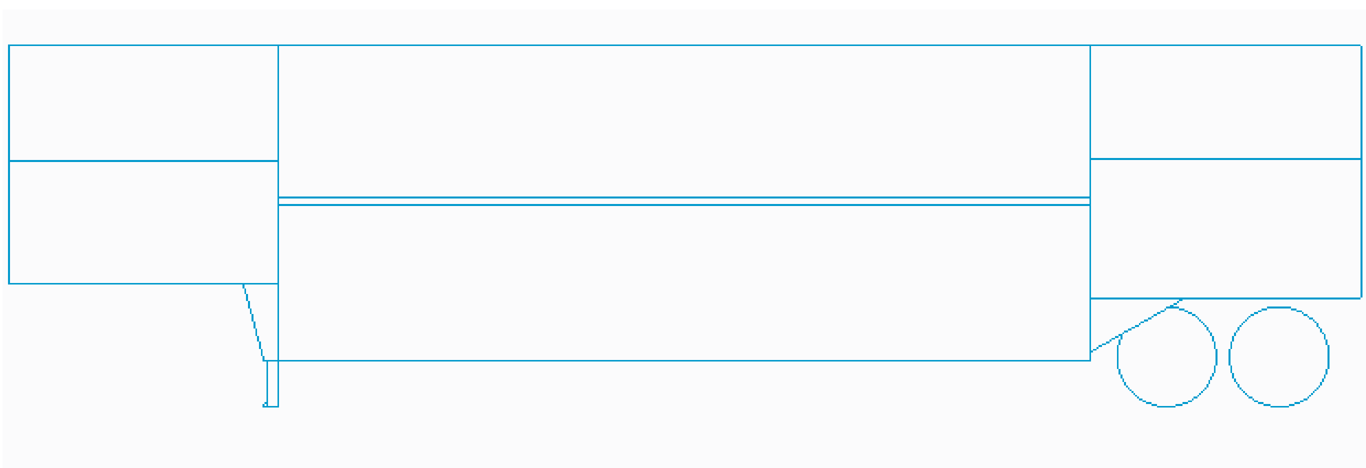


Figure 5. Internal schematic of standard pot belly trailer with double axle.

This design divides the trailer into the upper and lower nose, deck, belly, doghouse (also known as the jail), and the back of the trailer (Figure 5). These six compartments are not equal in floor area or height so there is some level of skill that the driver needs in order to properly distribute the animals based on space and weight within each compartment.

The deck and the belly can further be split by separation gates in order to keep the animals better dispersed within the trailer but this is normally only seen in long hauls for it is a tedious and somewhat dangerous process to set up for the driver must enter the trailer after the animals to set the gates.

There have been some modifications to the pot belly trailer in order to improve height and width clearances as well as loading and unloading measures but the “pot belly” portion of the trailer has remained the same. One of the most drastic changes has been the development of the “fat trailer”. Cattle are now fed to heavier weights as compared to previous decades and have been selected for larger frames which makes for an overall bigger animal. The fat trailer was designed to help combat height issues in the location with the shortest clearance, the nose. Instead of having the nose split into an upper and lower section, the fat trailer simply extends the deck forward into the nose compartment, leaving a small space (normally used as storage or left empty) underneath as shown in Figure 6. Some have also done away with the doghouse compartment to reduce weight, thus be able to haul more animals.

Fat trailers do allow for more clearance and space allotment in heavy weight animals but are less economically feasible when hauling young and/or light weight animals, for space allotment becomes an issue before maximum hauling weight is achieved resulting in a decrease in transport efficiency. Some trailers have been fitted with an adjustable nose so as to be able to convert between a feeder/fat and a fat trailer to counteract the negative attribute seen with fat trailers when not hauling fat or cull cattle.

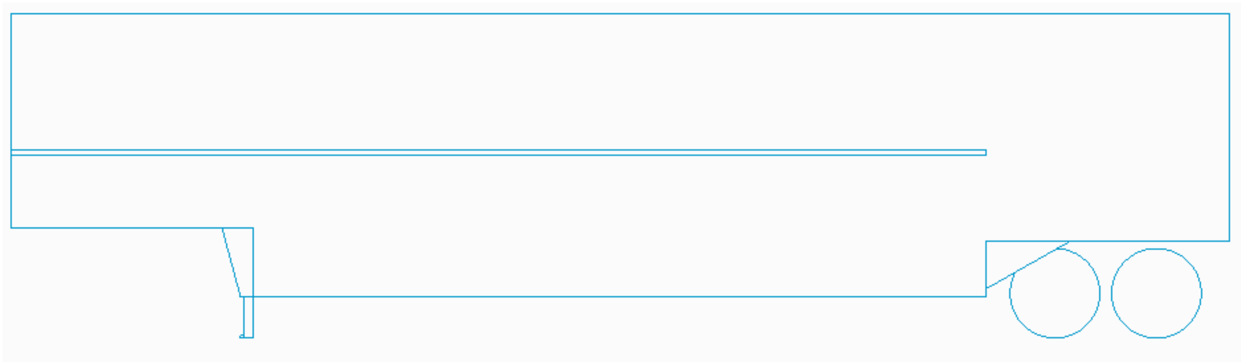


Figure 6. Fat trailer internal schematic.

(a)

(b)

Figure 7. Ramp system of pot belly trailers leading into the deck (a) and belly (b).

Animals are loaded into the trailers from the back by using an external ramp or load out system. The cattle are herded into the trailer where they are either walked up a ramp into the deck (Figure 7a), down a ramp into the belly (Figure 7b), or remain in the back compartment. In the case of smaller animals (calves, feeder cattle, pigs, and small ruminants), after walking up the ramp into the deck, the animals are herded to the front of the trailer where they are herded up or down a ramp to reach the two levels of the nose.

The ramp leading up to the deck from the back of the trailer was originally designed to lift up and slide under the top deck of the trailer. This ramp extends into the clearance space to go down in the belly, resulting in a four-inch-long area where the clearance is three inches less than in the rest of the space as highlighted in Figure 8. This can result in more back bruises in taller cattle.

Figure 8. Highlighted clearance issue when entering belly compartment.

The ramp leading into the belly goes down in between the back tires over the axle for maximum clearance, this portion of the trailer is difficult to modify without losing space efficiency. One solution to this issue has been to have the ramp leading up into the deck compartment hinge against the trailer wall on the driver's side and simply fold up when not in use, thus ensuring maximum clearance is achieved for the belly ramp. Other modifications have included pushing the deck back 0.23m (9 in.) thus increasing the belly ramp clearance by almost 0.13m (5 in.) Some "full back" trailers have the entire back open up as an entrance and have two large ramps come from under the deck so that the animals have the entire back end of the trailer as an entrance which some find reduces the initial confinement stress for animals in the deck but the belly ramp remains unmodified. Spread axle trailers are becoming much more popular where, instead of having two axles in the back right next to each other, there is a significant gap, increase the length of the back compartment by 1.2m (4 ft) and dispersing the weight more evenly. This style also supports tri-axle trailers where the third axle can be dropped down to support more weight. This style is very popular in trailers that haul along the United States/ Canadian border for each country has their own specifications on weight distribution which can be mitigated by these adjustable axle trailers.

2.2 Straight Deck

Straight deck trailers are rectangular in structure and can either have punch hole configurations along the sides or a slat configuration (rectangular inlets) as shown in Figure 10.

Figure 9. Straight deck trailer with slat inlets (Wilson Trailer, 2017b).

The body of the trailer sits on top of the axles instead of having the dipped belly section like that of the pot belly. This results in less vertical clearance, and also a less stable structure for the center of gravity for the trailer is higher. These trailers can be divided internally into either two (double deck; Figure 11) or three (tri-deck; Figure 12) levels.

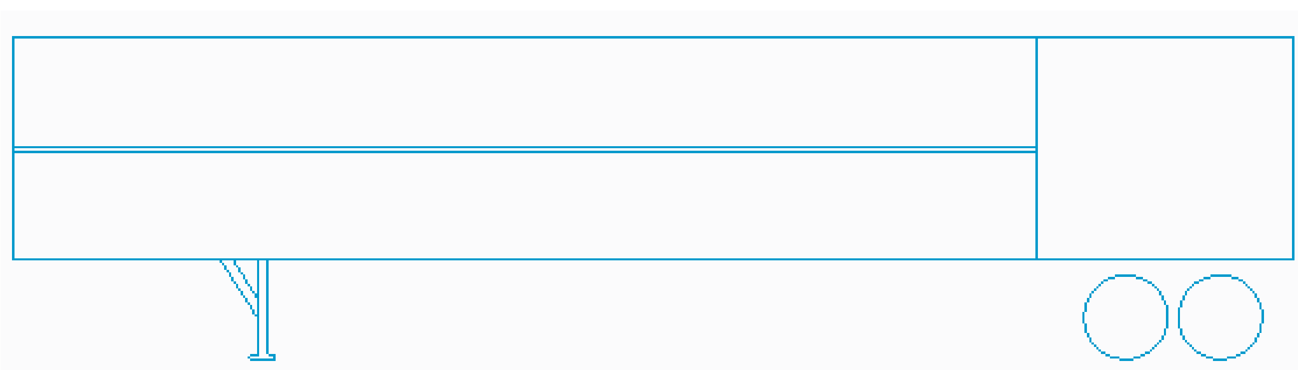


Figure 10. Double straight deck trailer internal schematic.

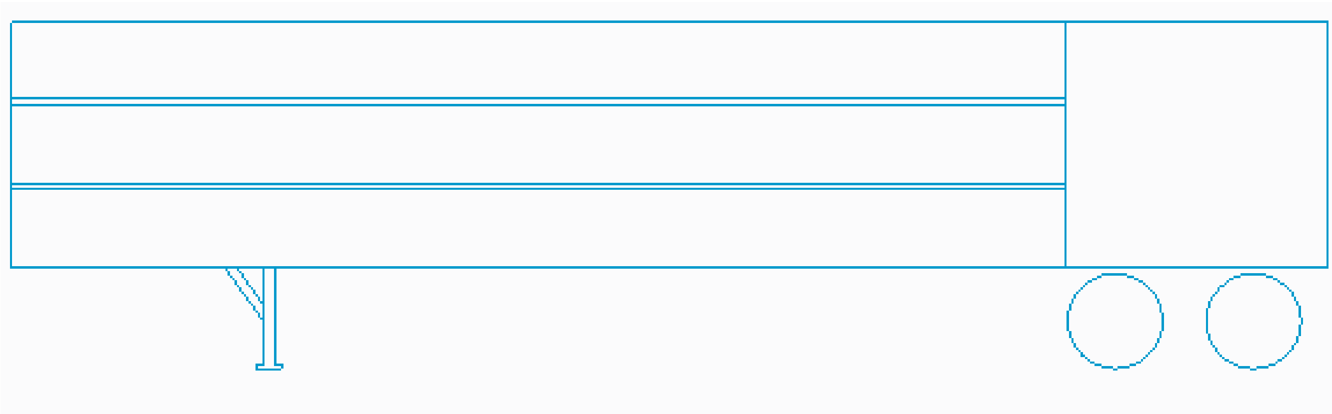


Figure 11. Triple straight deck trailer internal schematic.

Swine and sometimes small ruminants are the primary livestock hauled in these types of trailers. The animals are loaded in from the back by a ramp or load out system where they are either allowed to maneuver straight into the lower deck or they must walk up a ramp into the upper level(s). This removes the need to have a ramp to enter the lower level like in a pot belly trailer but there are still ramps that the animals must traverse. Biosecurity is an important topic when it comes to hauling swine and has an impact upon the trailer. Swine trailers will at least be thoroughly washed out but some will also go through a heat treatment step between loads where the empty trailer is driven into a full scale thermo-assisted drying and decontamination (TADD) system, also known as a "cooker", where the internal trailer temperature is brought to 71˚C for 30 minutes to kill off pathogens (Dee et al., 2005). Trailer modifications have also been made to reduce areas that are difficult to wash out the pathogen harboring fecal material.

2.3 Poultry Trailer

Poultry transport varies substantially from cattle or swine transport. The poultry are loaded into shipping crates, loaded on pallets, and are then loaded onto the trailer instead of being directly loaded onto the compartment. A fully loaded trailer is shown in Figure 13.

Figure 12. Poultry trailer with front and rear bulkheads fully loaded with crates (NFACC, 2017).

It must be noted that chicks are often loaded into enclosed and ventilated trailers to better regulate the internal conditions to reduce death loss but this process is time consuming and not economically feasible for hauling fully grown birds. Part of the loading density efficiency comes from crate height which is dictated by the size of the birds. This crate and pallet system allows for a more efficient use of space.

An empty poultry trailer is similar to a flatbed trailer used to haul non-animal products like machinery and supplies. The main difference would be the front and sometimes rear "poultry-style" bulkheads. Many trailers that have ramps that come off the back of the trailer for loading that flip vertical and make up for the rear bulkhead as seen in Figure 14.

There is also the difference of what are called "runners" and "coop stops" in order to further secure the pallets with the cages to the trailers. Trailers are either fitted with the roof structure or tarp in order to keep the sun off the birds in the topmost cages. Some will also have

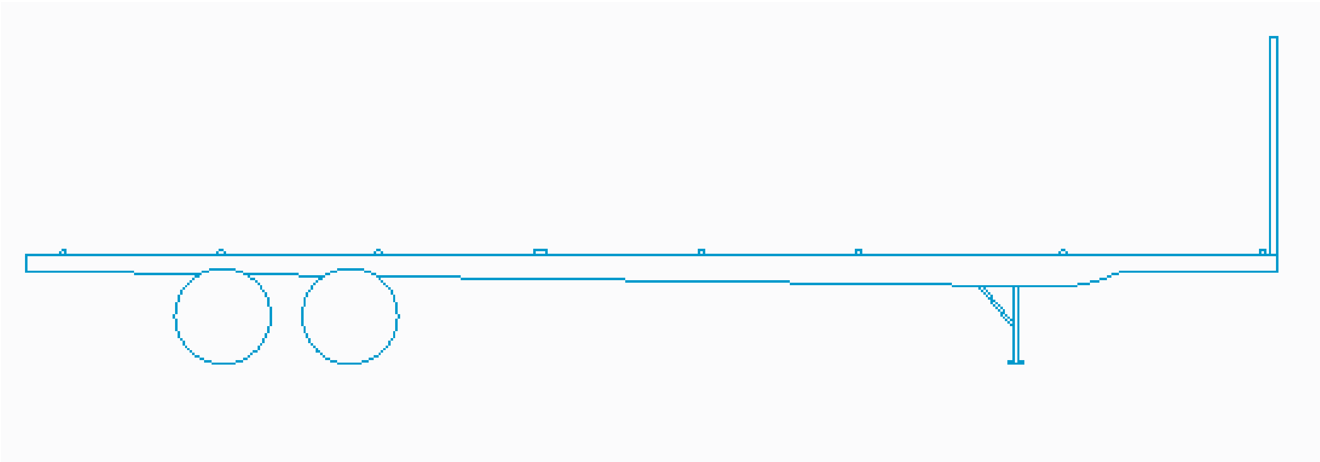


Figure 13. Poultry trailer with front bulkhead schematic.

tarps that drop down over the sides of the crate stacks to keep the chickens warmer during very cold or rainy weather conditions. However, this greatly reduces the airflow and increases heat and moisture levels around the birds. It was also stated that this keeps the chickens from view of the public during transport (CPEPC, 2017). It is common practice to have drivers park their trailers alongside banks of fans while waiting to offload at slaughter facilities to force air through the crates and cool off the animals. These fan banks are also normally housed under an overhang to extend the life of the fans but also to reduce the solar radiation influences and allowing for more effective cooling as well.

2.4 Enclosed Trailer

The European Union has much more stringent livestock transport regulations than the United States or Canada. Trailers in the European Union must include adjustable levels to accommodate different species heights, onboard feeding and watering systems, and an internal ventilation system that maintains a temperature range from 5°C to 30°C, and that the driver can monitor from the cab and that records the temperatures for the log books (EFSA, 2004). Airflow regulations were further specified in 2005 to a minimum of 40 air changes per hour and the slowest acceptable air speed of 4.47 m/s (EU, 2005).

Air and environmental quality regulations have not been set in place in North America but enclosed trailers are starting to make their way into circulation. A Canadian trailer manufacturing company, HarBra, has made advancements in trailer design by implementing an Italian design (Pezzaioli) that is a completely enclosed trailer with ducted air, adjustable deck height, and equipped with *in situ* feeding and watering troughs to improve the quality of animal transportation and to meet European Union regulations (Figure 15). There are other North American companies that are following this shift by enclosing trailers and using forced ventilation but are not currently implementing the feeding and watering troughs.

Figure 14. Pezzaioli enclosed trailer with cab-over semi (Pezzaioli, 2017).

These trailers utilize a “ground loading” system where ramps or load out systems are unnecessary except for a slight ramp that comes from the trailer to help smaller animals step up. The animals that will be transported in the upper level(s) of the trailer are loaded first and then the hydraulic system is activated to lift the entire level of the trailer up to the desired height and the second (and possibly third) set of animals are loaded underneath.

Figure 15. Pezzaioli enclosed trailer rear view (Pezzaioli, 2017).

This eliminates the stress of traversing steep and slick ramps and allows for more versatility of loading environments. This style of trailer has stayed mainly in Canada (especially in northern regions) and is considered to be more applicable for cold weather conditions when outdoor temperatures are too severe to allow for natural airflow and boards would be used to cover punch holes or slats anyways to keep the animals from becoming too cold, especially in smaller animals. There are issues with the overall weight of the trailer due to the overall design, hydraulic systems, and added water and feed weights. There have also been some questions raised with the water and feed trough responsibility and liability.

2.5 Research and Development Needs

Very little research has been conducted and published within North America regarding natural air flow in commercial livestock trailers. It would be beneficial to industry to evaluate the different trailer types with simulated animals, indicative to what is normally hauled within that trailer. Weight limits are currently under review which would allow for more research to be done in the areas of facilitated and mechanical ventilation.

2.6 Summary

Trailers are limited by height, width, and weight which varies by region. The trailers discussed are pot belly, straight deck, poultry, and enclosed trailers, with each type of trailer having characteristics most suited for specific species but are not species exclusive. The natural airflow within the trailer is indicative of air uptake in the rear of the trailer and outlet in the nose of the trailer near the truck attachment. This results in the back compartment being cooler than the nose for the majority of moving periods. There are different hole styles and patterns that can be implemented to alter the porosity of the trailer and can be further altered through the use of boards in cold weather to improve the internal climate.

The majority of the alterations to pot belly trailers are done to control clearance heights since larger animals are hauled in this type of trailer. Straight decks are altered for maximum head numbers through decks and axle spread. This style ensures that there is enough space to reach maximum weight limits since the animals are smaller. Poultry trailers are mainly used in chicken and turkey transport but other birds and other small animals can use transported using this system. Enclosed trailers are not as common within North America but are becoming more prevalent, especially in northern areas. These trailers are adjustable and can be used for medium to large animals, primarily swine and cattle. Trailers are continuously altering their established designs to improve animal welfare and ensure that carcass damage is minimal but commercial livestock transport remains relatively unchanged.

Chapter 3 - Cattle

Cattle, on average, are transported 4 to 6 times during their lifetime (Gonzalez et al., 2012c). The general flow of cattle starts with the animals being born on a cow/calf operation, weaned, and hauled to a sale barn where they are sold and transported to a stocker operation, grown for a period of time, transported to a feedlot for the finishing phase, and then finally transported to a slaughter facility. The United States slaughtered 28.8 million cattle and produced 23.7 billion pounds of beef in 2015 (USDA, 2016). In order to achieve these numbers, approximately 934,000 loads of cattle are transported to slaughter facilities each year with the weight of the animals ranging from approximately 500 to 725 kg (Fike and Spire, 2006). One study conducted in North America evaluated the effects of long haul transport (>400 km, 250 mi.) on over 14,000 loads of cattle transported and reported that the average time the animals spent in transport to be 15.9 hours, the average distance of these trips to be 700 km (435 mi.), and the internal trailer temperatures ranging from -42°C to 45°C (-43.6°F to 113°F; Hicks, 2012).

Transportation is considered one of the most stressful events that cattle must endure during their lifetime (Grandin, 2001; Kettlewell et al., 2005). The overall transportation process includes gathering and holding cattle before and after loading, loading time, time spent on trailer (stationary and moving), waiting to unload at destination, and finally unloading. The effects of stress vary according to the actual stressor as well as the magnitude and frequency of the source of stress (Marahrens et al., 2011).

Commercial cattle operations normally utilize straight deck or pot belly trailers (sometimes with modifications) in order to move cattle efficiently from one facility to another. Different procedures and equipment (particularly trailer type) are taken depending on the age and weight of the animals when they are transported, with each procedure yielding a different result. For instance, trucks hauling calves are more likely to use boards in cold weather to regulate internal temperatures based on the surface area to volume ratio of the animal. Another example is that calves and feeder cattle are able to be economically and safely loaded in all compartments of the trailer, whereas the nose compartment is often unused when hauling finished (also known as market weight) cattle due to the height of the animals and the loss of profit from the back bruising in low clearance regions. Similar issues are also seen when hauling dairy cattle even if they have not reached slaughter weight since their frames are genetically taller than that of the average beef cattle. Animal welfare is of utmost importance regardless of age, weight, or even species of animal being hauled but there are different ideal outcomes for each different category of animal. For instance, health and immunity are the primary focus when transporting calves and feeders, while carcass quality and profit preservation is the main objective when transporting market weight or finished cattle to the slaughter facility (Bosona and Gebresenbet, 2013). Body weight lost by an animal during transport, also known as shrink, can vary due to factors influenced by the animal's life stage, such as differences in diets, loading densities, and location of feeding facilities in relation to the destination (Nielsen et al., 2011). Due to these variances, this review presents a summary of literature evaluating animal welfare, profitability, and economic factors influenced by transporting finished cattle in the beef industry.

Previous research that evaluated cattle transport systems has contributed to improvements of animal welfare and beef products in the United States (Swanson and Morrow-Tesch, 2001; Fike and Spire, 2006; Cockram, 2007). The United States follow what is called the 28-hour law dictating the duration animals may be transported before being offloaded and allowed to rest. The 28-hour transport law was first presented as a guideline to the transport of animals by rail in 1873 and was established as federal regulation for the interstate transport of livestock by the USDA in 1918 (Goding and Raub, 1918). Slight modifications were made which included civil penalties, mainly the inclusion of fines ranging from $100 to $500 for each offense were put into effect in 1994 (USDA, 1994), but transport duration and other fundamental concepts have remained unchanged. Slow regulation changes in combination with the vast improvements made within European Union transportation systems have brought into question animal welfare concerns within the United States and Canada. Trailer companies in North America are seeing the change. One manufacturing company, HarBra, has made advancements in trailer design by implementing an Italian design (Pezzaioli) that is a completely enclosed trailer with ducted air, adjustable deck height, and equipped with *in situ* feeding and watering troughs to improve the quality of animal transportation and to meet European Union regulations. Regardless of means, the results of transportation should be a balance of profitability and welfare of the animal during transport (European Commission, 2001; CEC, 2005). The infiltration of European designs shows there could be grounds for the United States and Canada to reevaluate welfare concerns in transport and alter certain practices accordingly, while still maintaining economic feasibility.

3.1 Microclimate

The normal body temperature of an adult beef cow is 37.8°C but can range from 36.7°C to 39.1°C (98.0°F to 102.4°F; Merck Veterinary Manual, 2008). Cattle regulate their body temperature through evaporative cooling where heat is exchanged with the surroundings by a vapor gradient through the production of moisture (Gaughan et al., 2000). The efficacy of this process is determined by the air temperature and moisture gradient, vapor pressure, animal's surface area, posture, surrounding animals, and orientation in relation to air flow (Curtis, 1983). It is in part due to these attributes that calves are much more susceptible to cold stress due for their high surface area to volume ratio allows them to release heat more efficiently than larger cattle but also explains why market weight cattle are more likely to suffer heat stress for they cannot remove heat as quickly and effectively as calves. Another issue is that the ability of cattle to effectively utilize evaporative cooling is severely hindered by the presence of high humidity, which could lead to heat stress and could potentially become fatal (Hahn, 1999; Brown-Brandl et al., 2005b). Cattle transported in high stocking densities under warm environmental conditions have less air space around them and may be unable to dissipate enough heat to avoid heat stress (Jury, 2013). The Temperature-Humidity Index (THI) has been formulated as a way to ensure the safety of the animal by taking these factors into consideration and creating a value comparable to the "real feel" temperature using the following equation: $THI = (0.8 \times T) + [(\%RH/100) \times (T - 14.3)] + 46.4$ with "T" being the temperature in degrees Celsius and "RH" being the relative humidity (Nienaber et al., 1993; Gaughan et al., 2002). This formula is used to create the Livestock Weather Safety Index (LWSI) which is used as a standard industry chart that distinguishes different severity zones for THI values. These zones are defined as: normal or safe (<75); alert (75 to 78); danger (79 to 83); and emergency (>84; Figure 16).

This formula and subsequent chart recognizes that cattle are much more tolerant to cold temperatures as opposed to hot and humid conditions (EFSA, 2004). Therefore, transporting market weight cattle in hot weather conditions needs to be more closely monitored to ensure animal safety.

Temperature Humidity Index (THI)

Temperature (°C)	Relative Humidity (%) 20	30	40	50	60	70	80	90
40	84	86	89	91	94	96	99	101
38	82	84	86	89	91	93	96	98
36	80	82	84	86	88	90	93	95
34	78	80	82	84	85	87	89	91
32	76	77	79	81	83	84	86	88
30	74	75	77	78	80	81	83	84
28	72	73	74	76	77	78	80	81
26	70	71	72	73	74	75	77	78
24	68	69	70	70	71	72	73	74
22	66	66	67	68	69	69	70	71

Normal<75	Alert 75-78	Danger 79-83	Emergency >84

Figure 16. Temperature Humidity Index (THI) Chart adapted from Whittier (1993).

Gilkeson et al. (2016) identified the four major components affecting internal air flow: 1) vehicle speed, 2) wind direction, 3) vent area, and 4) the amount of blockage of inlets and outlets due to animal placement. The purpose of increasing ventilation is to provide the animals with fresh air while removing stale air, as well as excess heat and humidity (Kettlewell et al., 2001a; Fike and Spire, 2006). The movement of air within the trailer is partially dependent upon the porosity of the trailer, the punch hole placement, and if the animals are blocking the holes (Figure 17). A standard pot belly trailer has between 8.7% to 9.6% overall porosity depending on duffy (Wilson brand punch hole) or punch hole configuration, top vents of rear roll up doors, and number of roof hatches (Bryan, 2013).

Figure 17. Cow looking through punch hole during transit (Photo Credit: Heather Maude).

Based upon these differences, each compartment within the trailer has its own individual, yet internally homogenous, climate (White et al., 2009) with the porosity percentage and temperature (both ambient and core body temperature of the animal) inversely correlated (Bryan, 2013). In contrast, Camp et al. (1981) found that there was no difference between the trailer compartments when comparing animal shrink; however, duration and loading densities varied, as well as the age of animals used. In addition, only one temperature was taken and used as a point of reference for the entire trailer, which showed deviances from the research conducted by Bryan (2013) and Greer (2013).

External trailer modifications in the form of several “air scoops” comprising of a metal box with two sides removed fitted over the preexisting punch holes in standard pot belly cattle trailers (shown in Figure 18) to help facilitate air flow were tested by Giguere (2006). Inlet scoops were placed on one side along the length of the trailer and outlet scoops place along the other side of the trailer, thus forcing air the width of the trailer, perpendicular movement and natural air flow. Giguere (2006) found that ammonia was reduced by a minimum of 25% and could reach upwards of 46% reduction depending on the compartment of the trailer. The modified trailer was cooler 86% of the time, had lower ammonia concentrations by a least 1.2 ppm at every hour of sampling, and 0.6 to 1.0% less shrink than the than the trailers without the scoops (Friend, 2006; Greer, 2013).

Figure 18. Air scoops on the side of pot belly trailer (Giguere, 2006).

The results also showed a decrease in the amount of deaths; however, this concept was not considered a feasible option since the scoops created enough drag that there was a substantial increase in fuel consumption and it was deemed that the subsequent costs would negate the monetary benefits. This undesirable drag affect could be partially due to the placement and orientation of the scoops which were positioned to force air perpendicular to the direction of movement instead of mimicking and enhancing the natural flow of the trailer.

Passive ventilation systems rely heavily on truck and trailer movement in order to force air through the trailer. When trailers are stationary, there may be minimal or nonexistent cross breeze, which could result in a dangerous environment for the animals. The temperature inside the trailer can rise 1°C for every minute the trailer sets motionless (Bulitta, 2015; Xiong et al., 2015). Bryan (2013) found that the internal temperature during stationary periods can reach up to 10.5°C higher than ambient temperature and 9°C higher than ambient temperatures when moving. In addition, Muirhead (1983) reported there were areas of no air flow within trailers while the trailer was moving, creating pockets of stagnant air. Trailers with poor to no air flow can cause an accumulation of animal produced gases in addition to diesel exhaust fumes (Haag, 1945). Additionally, the natural effects of thermal buoyancy with hot air rising and also the top deck solar radiation exposure result in the belly having a lower THI value than the other compartments, coinciding with the findings of Stanford et al. (2011) but can also depend on the heat of the road and any heat that radiates from it. Regardless of location, any animal subjected to prolonged heat stress has a higher instance of tissue damage and mortality (Mitchell and Kettlewell, 2008; Jury, 2013).

The United States and Canada have implemented the use of bedding material like straw or sawdust as well as slats or boards to cover the sides of the trailer as a way to improve the internal climate in colder conditions to increase animal comfort. This practice is more prevalent in Canada where temperatures reach much lower values than what is normally recorded in the United States. Warren et al. (2010a) reported that almost 80% of Canadian trucks use some pattern of boarding or punch hole blocking and found that the use of boards during Canadian winters reduced the number of dark cutting carcasses. Gonzalez et al. (2012d) found an infrequent use of boarding in certain areas and stated this could be due to animals that sweat while in transport and then have health problems when the ‘wet animals’ are offloaded into cold conditions. This increase in humidity also caused concern over the internal microclimate. However, Goldhawk et al. (2015) reported that boarding increased the ventilation in moving trailers but decreased ventilation and air quality when stationary. It is to be noted that there are no boards that are placed over the back external wall of the trailer or the roll up door so this could potentially streamline airflow through the natural uptake areas, i.e., through the back of the trailer and out the nose. Another practice that is more variable is the use of bedding. The Canadian Codes of Practice recommends bedding if external temperatures get below 10ºC, which is not uncommon in Canada and the northern United States (Gonzalez et al., 2012c) in order to reduce cold stress, but does become an issue when it is time to clean out the trailer and dispose of the bedding.

3.2 Loading Density

The United States, Canada, and several other countries implemented transport regulations that require cattle trailers to fall within certain height, width, length, and weight restrictions. North America primarily uses commercial pot belly trailers for hauling cattle, pigs, and other ruminants as a standard size for the ease of loading and unloading at any given facility making loading weight the main limiting factor. Loading trailers by weight instead of by head creates an issue of space and is further compounded by the transport marketing system measuring as live weight per kilometer or mile (Whiting, 2000), resulting in each trailer being loaded as full as possible to increase economic profit, sometimes at the expense of the animals' welfare.

Cattle will naturally orient themselves either directly perpendicular or parallel to the movement of the trailer (Eldridge and Winfield, 1988; Lambooy and Hulsegge, 1988; Flint, 2013). Cattle do not normally orient themselves in a diagonal or “skewed” direction, but at higher loading densities (also known as stocking density), cattle have limited space to move and are unable to choose their placement. Some truck drivers use the general alignment in relation to the traveling orientation as a quick way to check if the animals are packed too tightly within a compartment. There have been reports (Tarrant et al., 1992) that the animals were skewed (diagonal) to the direction of trailer movement even at appropriate (medium) loading densities but this result could be explained by the abnormal airflow sometimes seen within the trailer with certain gate setups which would cause the cattle to orient themselves in the direction of the airflow as they would in an open space and not be aligned with the movement of the trailer. Regardless, a quantitative approach to determine appropriate stocking density at different finished weights, distance traveled, time on the truck, and during different environmental climates is needed.

Many researchers have tried to place a quantitative value to safe loading density so as to remove the ambiguity from the situation. Currently, the equation used to determine an appropriate loading density for cattle is space per animal (square meters) = $k*BW^{0.67}$ where k is the allometric coefficient, BW is the average body weight of the animal being transported (in kg) (FAWC, 1993). The higher the loading density the less space that is allowed per animal. Several researchers have determined the safe allometric coefficients for low, medium, and high stocking densities to be k-values of 0.026, 0.021, and 0.016, respectively, resulting in each 500 kg animal to have 1.67 m^2, 1.35 m^2 and 1.03 m^2, respectively, but have found industry practiced high stocking densities to have k-values of 0.014 to 0.015, and low densities have 0.018 to 0.046 allowing that same animal to have anywhere from 0.91m^2 to 3.00 m^2 of floor space (Randall, 1993; Petherick and Phillips, 2009; Schwartzkopf-Genswein, 2012). Gonzalez et al. (2012a) determined the optimal range for animal welfare of all weights and ages to be a k-value between 0.015 and 0.035 and may vary due to bruising and economic factors influencing carcass values. For instance, Australia has defaulted to a loading density with a k-value of 0.02 as a way to reduce the severe bruising seen at other densities and the costs associated with them, especially since their cattle are handled much less often and have more adverse reactions to humans than what is normally expected in the United States (Eldridge and Winfield, 1988). Still, improperly distributing animals can result in bruising penalties ranging from $1.30 to $4.03 loss per animal in North American markets (Schwartzkopf-Genswein et al., 2012). These costs are further compounded by regulation inconsistency issues seen with very large animals (fat and cull) and very small animals (calves) in their space allotment, thereby reducing the safety of the animal. Market weight and cull cattle tend to be allowed more space than necessary while calves are transported with high loading densities in order to reach maximum weight and thereby transport profit, even though there could be carcass price reductions caused by improper loading densities.

Abnormal behaviors are seen at loading densities that fall outside the optimal bounds (k-values of 0.015 to 0.035). The frequency of social interactions and exploratory behavior decreases, while aggressive behaviors and loss of balance increases with increasing loading densities (Jury, 2013). Tarrant et al. (1992) reported that high densities (k-value of 0.026) had greater incidence of bruising and low densities (k-value of 0.016) had more falls when compared to medium densities (k-value of 0.021). Another issue seen is that lower area allowances (i.e., higher loading densities) have less air flow around the animals resulting in lower air quality for the cattle (Muirhead, 1983; Hartung and Springorum, 2009). Currently, the Farm Animal Welfare Committee uses the formula $A=0.021BW^{0.67}$ to estimate the area needed for all transport durations. Grandin (2014) recommends different loading densities for long and short durations so that animals could lie down in transit with a lower likelihood of being trampled. For trips longer than 5 hours, Grandin (2014) recommends using the modified equation of $A=0.01BW^{0.78}$ in order to allow enough floor space for animals to lay down during long hauls to help relieve fatigue. This results in a 10 to 30% increase in area for animals of the same weight compared to hauling at high stocking densities (k-value of 0.015) but actually gives the animals less room if compared to the medium recommended k-value of 0.021 (Schuetze et al., 2017). It is to be noted that the k-values (coefficient) for each loading density remain the same regardless of equation or body weight of animal used (Grandin, 2014), the different exponential constant (0.67 vs. 0.78) is used to give animals the proper amount of area based on whether the animal would need to lay down or not.

3.3 Duration

Severe restrictions are placed on time that the cattle are allowed to be on a trailer and the time a truck driver is allowed to be actively on the road. As previously stated, transport includes gathering and holding cattle before and after loading, time spent loading and unloading, as well as the time the animals spend physically on the trailer (Jury, 2013). Each country has their own set of regulations as to how long animals are allowed to remain on the trailer before they must be offloaded and allowed to rest for a period of time. The United States has a 28-hour law (USDA, 1994), Canada has a 48-hour limit unless the destination can be reached within 52 hours in which case the truck can proceed to its final destination (CARC, 2001), and the European Union has a 30-hour limit (EU, 2005) before the animals must be offloaded and allowed access to food and water for a minimum of 5 hours before recommencing their journey (Schwartzkopf-Genswein et al., 2012).

Differences in transportation laws between North America and the European Union are not limited to just transit duration. In the European Union, the trailers haul fewer animals at a time and their laws are much more stringent on the internal modifications made to the trailer in order to ensure the animal welfare. Trailers in the European Union must include adjustable deck heights to accommodate different species, onboard feeding and watering systems, and an internal ventilation system that maintains a temperature range from 5°C to 30°C that the driver can monitor from the cab and that records the temperatures for the log books (EFSA, 2004). Airflow regulations were further specified in 2005 to a minimum of 40 air changes per hour and the slowest acceptable air speed of 4.47 m/s (EU, 2005).

Gebresenbet and Eriksson (1998) and Broom (2007) stated that long stints of transport and poor handling (Frese et al., 2016) in loading and unloading processes have a large impact on animal welfare and meat quality. These factors could be greatly improved by simply reducing the amount of time that animals spend on the truck. The risk of animals being unable to cope with the stress of transport increases as trip duration increases (Swanson and Morrow-Tesch, 2001). Gonzalez et al. (2012c) found that the likelihood of cattle death doubled when transport increased from 20 hours to 30 hours and increased by a factor of seven after 30 hours. Similarly, Coffey et al. (2001) found that the majority of shrink was seen in the first 3 to 4 hours of transport (that could be due to loss of gut fill). In addition, Knowles et al. (1999) found that half of the animals laid down after 24 hours of transport and suggested that some of the time restrictions should be lowered to avoid severe fatigue. Cattle can remain standing for approximately 15 hours before needing to rest in most conditions (Grandin, 2014). After standing for long periods of time, these animals had elevated concentrations of plasma cortisol which is linked with sleep deprivation in humans (Grandin, 2014). The more tired and unsteady the animals became, the more likely they were to slip and fall, which could result in potential injury of the animal and subsequent loss of carcass quality. In addition, there was a greater incidence of dark cutting beef in finished cattle that were transported less than 60 miles and greater than 180 miles (Jones and Tong, 1989).

Some researchers have reported that after an extended period of time on the road, the offloaded cattle will eat and drink before being reloaded for the next leg of the journey (Cooke et al., 2013), but others contradict this and state that it took longer than the required offload time before the cattle would eat and drink, making the stops less vital if the destination can be reached within an acceptable time frame, usually described as being within 4 to 5 hours (Kenny and Tarrant, 1987; Flint et al., 2014). Grandin (1997) stated that, in addition to extra unloading and loading stress, rest stops also increased the likelihood of the animals being introduced to new pathogens. This, in addition to other researchers' concerns, suggests the question of the validity of transport time limits and the benefits of rest stops (Ellis and Ritter, 2006; Fisher et al., 2009; Tucker et al., 2015). Gonzales et al. (2012b) found that, on average, fat cattle experienced delays of 1.98 ± 0.226 hours which was the shortest duration when compared to calves, feeders, and cull cattle. These delays were only recorded as in transit stops and time spent waiting at point of origin or destination were not included in these values.

3.4 Animal Behavior

Typically, cattle are finished in a feedlot on high concentrate diets, resulting in a rapidly increased rate of gain and improved carcass quality but, unintentionally, also a thicker insulating fat layer (Brown-Brandl et al., 2005a). Mature animals naturally have a lower surface area to volume ratio than that of younger animals, resulting in less efficient heat exchange (Finch, 1986). When this is combined with the extra insulated fat layer and the high energy diet, the animals are able to withstand colder temperatures quite well but can have extreme difficulties when the weather turns hot and/or humid. Cattle have several thermal zones that impact performance, which are the thermal comfort zone (TCZ), the thermal neutral zone (TNZ), and upper and lower critical zones (Figure 19). Animals are most efficient and have the highest performance when temperatures lie within the TCZ, usually ranging from 5°C to 20°C (41°F to 68°F). The TNZ, which is the temperature range at which the animals do not need to expend extra energy to maintain body temperature and homeostasis, ranges from 0°C to 28°C (32°F to 82.4°F), encompassing the TCZ (Hahn, 1999; EFSA, 2004).

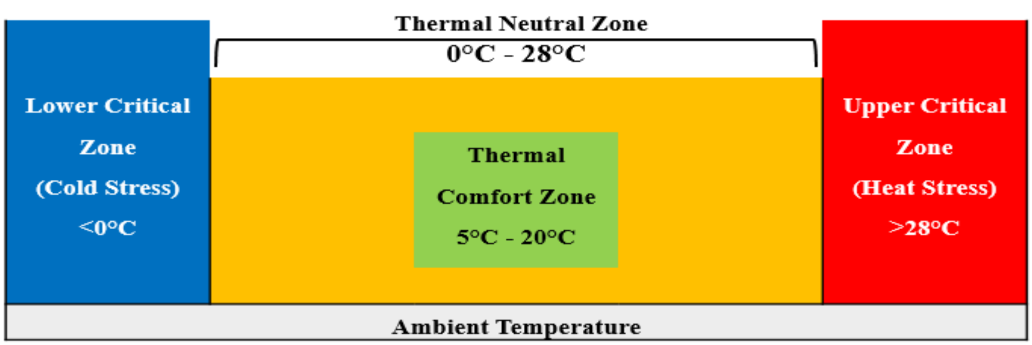


Figure 19. Thermal zone diagram.

Animals must expend extra energy by sweating if temperatures are in the upper critical zone and by shivering (and huddling together if possible) if temperature lies in the lower critical zone.

Gonzalez et al. (2012b) found that animals were more likely to become non-ambulatory and lame during transport when temperatures were outside the TNZ. This means that higher critical temperatures (heat stress) or lower critical temperatures (cold stress) can directly impact the health of the animal.

A stressed animal is one that is forced to make abnormal or extreme changes in physiology or behavior in order to withstand the detrimental environmental aspects (Stermer et al., 1982). The effects of stressors depend upon the type, duration, and intensity of the stress (Ferguson and Warner, 2008). Specific stressors during transport are water and food deprivation, noise and vibration from the trailer, human handling, forced physical effort, fatigue, novel environment, potential gas exposure, and commingling (Appleby et al., 2008; Terlouw et al., 2008; Bulitta, 2015). Notably, cattle are natural prey animals and will not always physically exhibit an indication of stress but can still experience the detrimental effects of stress (Von Borell, 2001).

Cattle response to stressful environments can be divided into physiological and behavioral changes. Physiological stress includes (but is not limited to) increased heart and respiration rates, elevated body temperature and blood pressure, and changes in biochemical markers such as creatinine, lactate, cortisol, neutrophil counts, and glycogen mobilization (Broom, 2003; Fazio and Ferlazzo, 2003; Tucker et al., 2015). Animals can become accustomed to stressors but the recovery period from the initial stimulus can vary. For instance, Grandin (1997) reported that a stressed animal can take up to 30 minutes for its heart rate to return to normal levels after the initial stressor. Behavioral changes that can be observed in response to stressful environments may include exploration (smelling and licking), aggressive behavior (pushing, fighting, threatening, and head butting), non-aversive behaviors (ruminating, increase of ruminal pH and rate of passage, and laying down), and loss of balance (shifting and struggling) or footing (Galyean et al, 1981; Kenny and Tarrant, 1987; Jury, 2013). With changes in physiology and behavior, not only is animal welfare jeopardized but there are alterations to carcass parameters such as shrink, bruising (which also affects hide quality), and incidence of dark cutting beef that result in lower quality products and lost profit (Tarrant et al., 1988, 1992; Kreikemeier et al., 1998; Warren et al., 2010b).

Shrink was earlier defined as the weight lost by an animal during transport. This includes the digestive tract contents that are evacuated during the trip making up the "gut fill" and also the reduction of water from within the animal's muscles also known as tissue shrink. The average "pencil" shrink is usually figured to be 4% during transport but can easily reach dangerous conditions with prolonged stress and environments with very high THI (Goldhawk, 2014). In fact, very extreme cases of shrink have been reported being up to 21.8% of the total animal's weight with prolonged transport time (>40 hours) and high internal trailer temperatures (46°C; Gonzalez et al., 2012d). Coffey et al. (2001) reported tissue shrink had the potential to account for almost 60% of the total weight lost during transport (with the other 40% being gut fill), but these cases often result in the death of the animal. Higher rates of shrink result in an increase in what is known as "dark cutters." Dark cutting beef, also referred to as dark, firm, and dry (DFD) beef, is the result of the mobilization of glycogen which decreases the amount of lactic acid produced post mortem which increases the pH of the meat and also the amount of water within the muscle tissue, where the increased water refracts light differently giving it the characteristic dark color (Scanga et al., 1998). Dark cutting beef has no nutritional difference than non-dark cutting beef but the grainy texture, sticky consistency, and reduced shelf life tend to repel retailers and consumers causing packing facilities to dock the price up to $6.08 per carcass which can be a substantial amount when feedlots have very tight margins of profit (Schwartzkopf-Genswein et al., 2012).

Cattle that present severe stress behaviors are diagnosed with what is called fatigued cattle syndrome (FCS). Symptoms of FCS are most notable when cattle arrive at the packing facilities and are indicative of cattle appearing fatigued. Animals with FCS are often lame, reluctant to move, and slow moving even after exiting the trailer (Thomson et al., 2015). Animals with FCS had greater serum lactate and creatine kinase concentrations, lower blood pH, and higher incidence of muscle tremors than animals without FCS. This is the result of the animal being subjected to stressors over prolonged periods of time like those seen during transportation especially in hot ambient temperatures (Thomson et al., 2015). All transport stressors like those of vibration, poor air quality, general fatigue, heat, humidity, etc. become compounded over time and have become a significant animal welfare concern (Ritter et al., 2005). FCS is a detrimental condition to the welfare of the animal and also to overall profitability.

3.5 Research and Development Needs

Research has been conducted in several areas of interest discussed in this paper, however, this research is not limited to market weight cattle transport. The majority of cattle are transported several times throughout the production process which can result in different outcomes based on animal size and transport objectives for each transport event. Research conducted with calves can be utilized when evaluating finished cattle transport, but the studies need to be done with finished cattle to ensure the results apply to all scenarios.

Airflow or lack thereof is a major stressor in all ages of cattle. The general airflow of the trailer has been established but the effect of animal size on airflow remains ambiguous. This size attribute could differ based on the size of the animal (i.e., calves and fat cattle) to different species. This could potentially affect loading density within the trailer and could be altered on a compartment by compartment basis to account for air movement and heat accumulation.

3.6 Conclusion

Transport is necessary but detrimental to animal welfare and meat quality. Close to a million loads of cattle are processed every year and can be transported long distances before they arrive at slaughter facilities. Different styles of trailer and regions of transport affect the welfare of the animals being transported. Microclimate affects how well animals can maintain internal homeostasis. This is also contingent upon the internal air flow and if the truck is in motion. The more time the internal trailers temperatures stay within TCZ or TNZ and the further away from critical temperatures, the less heat or cold stress the animals will endure. Loading density also influences animal welfare but dictating how much space each animal has according to the suggested equation of $k*BW^{0.67}$ and using different k-values to reach different densities. Loading density also affects how much air is able to pass around the animals, thus cooling them and also how much radiant heat is exchanged from animal to animal. The social interaction of the animals decreases while aggressive behaviors increase as loading density increases, meaning that the tighter the animals are packed into the space, the more stressed and aggressive they become. Transport time is heavily regulated depending on country and it a major point of contention when it comes to animal welfare during transport. Currently, transport time is dependent on distance to slaughter and also the balancing of profits for animals may be transported further, if the producer determines other slaughter facilities will pay more and the animals can still maintain value over the journey. Overall, there are many areas that need further research to understand the impact upon animal welfare and carcass quality.

Chapter 4 - Swine

Pigs are transported only one to three times in their lives (USDA NASS, 2012). They may be transported from a farrowing barn to a nursery to a finishing barn and then finally to a slaughter facility. Pigs are normally hauled in pot belly trailers or in straight deck (with either two or three levels) trailers. A survey of general commercial swine transport practices to slaughter facilities showed that approximately 50% of the loads were hauled using pot belly trailers and the other 50% used straight deck trailers (type of straight deck was not specified; Sutherland et al., 2009).

Speer et al. (2001) estimated that 80,000 pigs die due to transport to slaughter facilities (70% on the truck and 30% in lairage) and with each pig costing approximately $100 per head, losses due to transport can cost the United States pork industry over $8 million per year. The percentage of dead on arrival (DOA) animals was 0.19% and was directly related to external temperatures in a study conducted by Sutherland et al. (2009). Ritter et al. (2009) found that 0.25% of pigs in the United States die during transport and that 0.44% of them arrive at slaughter facilities non-ambulatory, while Haley et al. (2008) reported 0.12% transport deaths in Canada. These numbers show that transport does have a detrimental effect on animal welfare and the exact cause of the stress must be evaluated with the hopes of potentially resolving the issue. Transportation at least from farm to slaughter facility is necessary in industry, regardless of species, and cannot be done away with so certain aspects need to be researched to fully understand which aspects need to be altered and/or improved in order to find balance between the welfare of the animals and economic feasibility.

4.1 Microclimate

Pigs are homeotherms, like the other livestock species discussed in this report, and are very susceptible to heat stress. Pigs have sweat glands but many are inactive or very inefficient (sometimes due to being "plugged"), therefore the animals must utilize respiration and surface heat removal instead (Lucas et al., 2000).

Internal body temperature of swine ranges from 28°C to 41°C (82.4°F to 105.8°F) depending on the age of the animal, genetic traits, environmental upbringing (i.e., environmental stressors; Lambooy et al., 1987). According to the Merck Veterinary Manual (2008) the average rectal temperature of a fully-grown pig ranges from 38.7°C to 39.8°C (101.7°F to 103.6°F) and has a resting heart rate of 70 to 120 beats per minute (bpm). The resting respiration rate ranges from 32 to 58 breaths per minute but is highly dependent upon external temperature and other environmental conditions due to the lack of effective sweat glands. The middle of the thermal neutral zone for swine lies at about 16°C (60.8°F) but the zone can range from 8°C (46.4°F) at the lowest bound and reach upwards of 17.4°C to 23.3°C (63.3°F to 73.9°F) for the highest bound depending on the animal and the referred to literary source. The upper and lower critical temperatures, also known as threshold temperatures, are 5°C (41°F) and 30°C (86°F), meaning that any conditions that result in the animal experiencing these conditions for any length of time exposes the animal to either heat stress or cold stress and should be avoided if possible (Fiore et al., 2012). Williams et al. (2012) suggested that animals not be transported if ambient temperatures will exceed 35°C (95°F) in any part of the journey. Fitzgerald et al. (2009) developed an equation to predict market weight pig mortality (x) as $0.0102x+0.000541x^2$ per one unit increase of THI.

Commercially grown pigs are primarily raised in indoor environments with as few stressors as possible. When it comes time to be loaded, the pigs are herded through the barn to a loadout dock where they are forced to walk up the inclined ramp and into the trailer. Heart rate ranges from 84 bpm to 173 bpm with an average of 120 bpm during transport which is steadily above resting heart rates (Sommavilla et al., 2017). The stress from this event and the physical exertion results in an environmental temperature spike due to the body heat given off by the pigs. Immediately after departure there is an increase of 16°C to 20°C internal trailer temperature as reported by Kettlewell et al. (2001a) and Ellis et al. (2010) recorded initial spikes from 12°C to 22°C. Relaxed pigs in a comfortable environment produce approximately 1.5W/kg (watts per kilogram) according to Mitchell and Kettlewell (2008) but Brown-Brandl et al. (2004) recorded heat production in grow-finish pigs to follow the equation of $W/kg= (14.95 \pm 1.08)m^{(-0.40 \pm 0.02)}$ which would hold true to the findings of Mitchell and Kettlewell (2008) for animals weighing approximately 95 kg (close to current market weight) but would vary for over and underweight animals. It must be noted that as body mass increases, heat production decreases in a smooth curve, not in a linear fashion so the Brown-Brandl et al. (2004) equation is a more accurate prediction of heat production than the direct correlation assumed by Mitchell and Kettlewell (2008).

Heat generation by a market weight pig at the initiation of transport is about 211±31W per head but decreased to 138±13W as the journey progressed and general respiration released 0.0504g/s of water per animal after the pigs calmed down from loading (Kettlewell et al., 2001b). Pigs tend to settle down after 2 to 3 hours in transport after thermal stability is established (Kettlewell et al., 2001a). This slows the rate of heat production within the trailer but the trailer continuously warms as transport time progresses if no intervening measures are taken.

Heat stress is a primary concern in hauling most livestock species but especially pigs. Researchers have argued about the use of vents, fans, and sprinkler systems as well as combinations of the three as ways to improve the environmental quality within the trailers. Lambooy and Engel (1991) found that using variable ventilation by controlling vent openings to reduce animal stress and improve meat quality was only successful when used in conjunction with a sprinkler system. Only using the vents positioned in the nose of the trailer is not enough to effectively cool the animals and other methods must be implemented as well. The use of sprinkler systems within the trailers when ambient temperature was above 37°C (98.6°F) resulted in a decrease of down and dead (D&D) animals by 0.188% (Lambooy and Engel 1991). Even though sprinkler systems reduced transport losses, these systems vary in popularity for the system itself increases the overall weight of the trailer as does the water tank but there is also the added maintenance of the system. Some environmental control methods completely exclude the use of sprinklers to reduce weight and other transport issues seen with the systems. Warriss et al. (2005) reported that natural ventilation and allowing the animals to thermoregulate was more effective in cooling the animals than fan-assisted ventilation, whereas Averos et al. (2010) found that mechanical ventilation by fans oriented so as to draw air out of the trailer reduced death loss during transport. These differences could be due to fan placement and orientation as seen with the air scoop studies done with cattle (Giguere, 2006) and how the fans complimented or contradicted the natural ventilation patterns of the trailer.

Regardless if the pigs are transported in a pot belly or a straight deck trailer, air uptake occurs in the back of the trailer and exits towards the nose or front. Ellis et al. (2010) found that on average, the nose of the trailer had higher temperature than the rear of the trailer for all four seasons of that given year. Sommavilla et al. (2017) found differences in creatine kinase concentrations depending on compartment of the trailer the animals were transported in. Reports of increased number of bruises were seen on pigs that were transported in the rear compartments of the trailer (Dalla Costa et al., 2007). This could be due to the increased ventilation in these areas keeping the pigs comfortable enough for them to exert their energy and present more aggressive behaviors, instead of suffering from heat or cold stress.

Boarding is a common method used in both pot belly and straight deck trailers to combat cold stress conditions during transport especially in northern regions. The term "boarding" is used to describe the plugging of the punch holes with individual plastic disks or, more frequently, the placing of slats alongside the trailer to block the punch holes as seen in Figure 20 and 21.

Figure 20. Spread axle straight deck trailer with boarding slats (Wilson Trailer, 2017b).

Figure 21. Up close view of boarding (Wilson Trailers, 2017b).

Boarding is intended to keep internal trailer temperatures higher than ambient and reduce cold stress and frostbite. The ears of pigs are valuable in the pet treat industry and are particularly prone to frost bite and will freeze off in especially cold or prolonged exposure. Researchers have suggested that trailers should be boarded to 95% when external temperatures fall below -6°C and should be completely removed above 10°C, and used variable percentages between these temperatures (McGlone et al., 2014). This practice is primarily used in the transport of pigs, small ruminant species, and young cattle.

4.2 Loading Density

Pigs that are transported in pot belly and double deck straight deck trailers have roughly the same amount of area to utilize. Triple straight deck trailers have 30% more room distribute the animals across but also raises the center of gravity higher. Drivers must consider the weight of the pigs, amount of usable space, trailer type, and overall transport safety when loading animals.

Loading density for pigs is more often reported on a per head basis, which is different than cattle which are reported using weight basis. For instance, a loading density study was conducted using the densities of 0.66 m^2, 0.44 m^2, and 0.33 m^2 per pig (market weight) and found that muscle pH increased when stocking density increased (Lambooy et al., 1985). Petherick and Phillips (2009) recommended the use of allometric equations in order to give pigs the proper space during transport by evaluating weight instead of utilizing a per head number. The loading density equation proposed by Petherick and Phillips (2009) is $0.027 \times (BW)^{0.66}$ and would allow animals the freedom of movement and would allow for air movement around the animals.

Fitzgerald et al. (2009) found that over 2.05 million pigs were evaluated from 12,333 loads of animals that average pig loss was 0.85% per trailer and that loading density accounted for the majority of the variance in pig losses. Increasing the loading density by 50 kg/m^2 resulting in 0.53% increase in pig mortality, and increasing the density by 100 kg/m^2 caused 0.74% more deaths per trailer (Fitzgerald et al., 2009). Warriss et al. (1995) recommends a loading density of 0.35 m^2/100 kg to 0.39 m^2/100 kg which would allow each animal 0.39 m^2 to 0.43 m^2 of room. The average densities found by Fitzgerald et al. (2009) ranged from 212 kg/m^2

to 339 kg/m^2 (0.47 m^2 per animal to 0.30 m^2 per animal of market weight) and resulted in a 7.55-fold increase in death when comparing the minimum density to the maximum.

Pigs become fatigued during transport and it was found that animals with allowable (lower) densities laid down after 2 hours of transit (Lambooy et al., 1985). However, not all pigs are able to lie down if loading densities are higher than 235 kg/m^2 (0.47m^2 per head; Guise and Penny, 1989; Lambooy et al., 1985) meaning that there could be a need to formulate a different equation or loading practice for trips that have durations longer than 2 hours. The following equation was determined to estimate pig mortality in relation to loading density as $0.0102x+0.000541x^2$ per 0.0191 kg/m^2 of loading density (Fitzgerald et al., 2009).

Mixing of unfamiliar animals results in unsettled and sometimes aggressive behaviors especially in confinement with increased stress factors. Shifting and climbing behaviors took place at all stocking densities but the frequency at which these actions occurred increased with loading density (Guise et al., 1996). If more space (i.e. lower loading densities) than 0.35 m^2/100 kg is allowed skin damage due to fighting, falls, and trampling increases (Barton Gade, and Christensen, 1998).

4.3 Duration

Swine, like cattle, have variable journey lengths based on location to the processing facility and also the pricing at the facility. Swine (and other livestock) producers are sometimes willing to transport their pigs longer distances if it means that they will increase their profits. This can vary by growing facility or even by lots of pigs within the same facility. Duration of trip is as much a function of distance as it is of economic value and profit.

It is logical to think that long journeys have a much larger and linear impact on animal welfare and meat quality than short journeys but Werner et al. (2007) found that this is not always the case. The percentage of DOA pigs increased for trips lasting longer than 30 minutes but decreased from 5 to 11 hours and then proceeded to increase again (Sutherland et al., 2009). It was thought that this may be due to the initial stress of loading and the time the animal has to recover before being offloaded (Lambooy, 2014).

Mota-Rojas et al. (2006) measured the amount of shrink seen when pigs were transported for long distances and reported 8 hours to have 2.7% shrink, 16 resulted in 4.3%, and 24 hours presented 6.8% shrink. Pig present altered lactate, hemoglobin, and hematocrit levels as well as lower red blood cell count during transport and it was also found that drip loss decreased as transport time increased (Chai et al. 2010). Pigs can also suffer motion sickness and will potentially vomit during or after transport (Bradshaw and Hall, 1996; Bradshaw et al., 1996). Randall (1992) cites this illness to low frequency vibration and Guise (1987) warns that the pigs may choke on or aspirate the vomit, leading to death. Feed but not water is often restricted 12 or more hours before transport in order to avoid this issue overall (Averos et al., 2008). Fat breakdown commenced after 9 hours without feed and liver glycogen stores were used within the first 18 hours of transport resulting in a weight loss of 0.21% per hour (Brumm et al., 2005; Warriss and Brown, 1983).

Pigs are much shorter than cattle and are able to be transported in a variety of trailers. Dalla Costa et al. (2007) found that there was no difference in bruising amount when comparing a single deck trailer to a double deck straight deck trailer. Mota-Rojas et al. (2006) conducted a study in Mexico in the summer and based upon animal welfare, meat quality, and animal deaths reported that swine transport should not exceed 16 hours. Stress in pigs results in the utilization of glycogen stores and rapid acidification post mortem resulting in pale, soft, and exudative (PSE) meat (Tarrant, 1989). Allowing the pigs to rest for 2 to 4 hours after transport and showering them to reduce body temperature can result in a decrease in the incidence of PSE meat (Malmfors, 1982; Smulders et al., 1983). Pork can also present a similar issue to cattle with DFD (dark, firm, dry). Both PSE and DFD pork is unappealing to customers in its whole state and it difficult to incorporate into processed products due to the different pH and water holding capacity, so most of this undesirable meat goes into pet food products, substantially decreasing the profit on that animal.

4.4 Behavior

Pigs have a specific "coping style" that includes adapting, avoidance behavior, and passive acceptance but, when these strategies can no longer suffice, the term "stress" is used (Lambooy, 2014). Stress activates the pituitary-adrenal system and the sympathetic adrenal medullary system that results in deviations from normal functioning. This increases body temperature, heart rate, and respiration rate (Broom and Johnson, 1993). Other physical indications of stress include open mouth breathing, muscle tremors, and skin discoloration (Pilcher et al., 2011).

The general mixing of unfamiliar animals at the time of loading is enough of a change and stress for the animals that the result is an increase in fighting and other aggressive behaviors while waiting to load and also during transit (Gosalvez et al., 2006). Ritter et al. (2009) found that handling behaviors during loading can affect temperature and blood acid balance of the animal. These issues and stressors arise even before the truck and trailer begins to move. Once the trailer is heading towards its destination, all transport stressors like those of vibration, poor air quality, general fatigue, heat, humidity, etc. become compounded over time and have become a significant animal welfare concern (Ritter et al., 2005).

Pigs transported in pot belly trailers performed better during and after transport and the environment maintained lower temperatures than in straight deck trailers (Sutherland et al., 2009; Goumon et al., 2012). It must be noted that animals that were unloaded off of straight deck trailers had fewer physical indicators of stress than those off of pot belly trailers, possibly due to fewer ramps for the animals to navigate (Sutherland et al., 2009). Many researchers agree that any internal trailer ramps or load out systems should not be angled more than 20º for loading or unloading in order to reduce stress during these events for any animals, not just swine (Fraser and Broom, 1990; Grandin, 1981; Phillips et al., 1988; van Putten and Elshof, 1978).

Figure 22. Picture of loadout for commercial livestock trailers (Photo Credit: Brute Cattle Equipment).

Van Putten and Elshof (1978) found that as ramp angle increased, so did heart rate of the pigs traversing them and Mayes and Jesse (1980) stated that heart rate is higher when going up the ramps as compared to walking down them.

Transportation processes can initiate fatigued pig syndrome (FPS) which can cause further distress to the animal or even death (Tarrant, 1989). This syndrome is similar to fatigued cattle syndrome (FCS) in that the animals are reluctant to move, are slow moving when they begin walking, and give other physical indicators of stress. FPS is also characterized by splotchy skin, panting, and vocalization.

4.5 Research and Development Needs

Pigs are transported fewer times than cattle, therefore transportation research is primarily conducted with larger and older animals. Pigs are commonly transported in two different trailer designs. Airflow evaluations would not only be beneficial in pot belly trailers but also in straight deck trailers. This also lends itself to the evaluation of slats versus punch holes and different effects of porosity on airflow within the trailer. Boarding patterns can also be tied with this analysis. Another aspect to be explored is whether or not the hydraulic deck lift of the enclosed trailer is less stressful to the animal than a standard ramp system.

4.6 Conclusion

Transport losses can amount to millions of dollars when hauling swine. Thermal zones can largely impact the welfare of the animal, especially in cases of heat and cold stress. Fitzgerald et al. (2009) developed an equation to predict pig mortality as a function of THI that can also be applied as a function of loading density. The use of sprinklers and/or fans to improve the welfare of the animals is heavily debated by many researchers. Compartment location also had an influence on animal welfare. As loading density increased, as did the muscle pH and stress of the animal. Several different equations and solutions have been suggested to correct loading density inconsistencies. Similar to cattle, as duration increases, as does the shrink percentage as much as 0.21% per hour (Brumm et al., 2005). All these factors affect how pigs are able to cope with the stress of transport. Increased stress can lead to fatigued pig syndrome (FPS) which take intos account the welfare of the animal. After these issues manifest themselves the carcasses of the animals are often found to have PSE characteristics meaning that the meat quality decreases and becomes pale, soft, and exudative, resulting in further profit losses.

Chapter 5 - Poultry

Poultry production within the United States and Canada primarily focuses on chickens and turkeys but there are smaller sectors made up of pheasants, quail, duck, and squab that have a place in the specialty orders market, primarily high quality restaurants. Commercially grown chickens and turkeys are often hatched and then transported to growing facilities where they reside until the time to be transported to slaughter. Other facilities will hatch their eggs on site making the first and last time the birds are transported will be to slaughter facilities. “Broiler” is the term used to describe male and female birds raised specifically for meat while “end of lay” are birds used for egg production but have now reached the end of productivity (similar to cull cattle). Broilers are normally processed (i.e., sent to slaughter) from 35 days to 41 days of age and range from 1.75 kg to 3.5 kg, depending on the market (Tuyttens et al., 2014). This short production cycle allows for extremely large quantities of birds to be produced in short periods of time and also allows for complete turnover of chicken coops every few months which increase biosecurity. Currently, yearly broiler chicken production greatly exceeds 44 billion birds every year and is constantly increasing (USDA NASS, 2014). Turkey processing fluctuates with season with the majority of whole turkeys being consumed around Thanksgiving and Christmas holidays but with the increase of processed lunch meat, 239 million turkeys were processed in 2013 (USDA NASS, 2014).

Poultry are raised in barns with uniform conditions with all environmental aspects controlled including temperature, humidity, air flow, and light intensity for the entirety of their lives. This whole uniform aspect undergoes complete upheaval, usually for the first or second time depending on the hatchery set up, when the poultry is transported to slaughter facilities. Vibration, noise, daylight, people, temperature, overcrowding, and several other aspects of transport can be completely new to the birds and increase the stress level. It is to be noted that, like pigs, researchers have reported higher death loss during loading, unloading, and wait times in lairage when compared to deaths during transport (Ritz et al., 2005).

Poultry are rarely handled throughout their lives resulting them being more prone to negative effects during the transport process. This includes gathering, handling, being placed in crates and stacked, loading of the crates, transport, unloading all while being deprived of food and water. These stressors can impact animal welfare as well as meat quality characteristics such as color, texture, and protein functionality (Dadgar, 2010). Wet or even just damp feathers is also an issue in cold weather and greatly increases the likelihood of poor welfare and dead on arrival (DOA) animals (Ritz et al., 2005).

Figure 23. Broiler chickens in transport crates (Dam et al., 2016).

Poultry transport involves capturing and loading the birds into crates (Figure 23), stacking the crates onto a pallet and loading the stacks onto poultry trailers with a design similar to a flatbed trailer with ridges to lock in the pallets. There is also a framework to hold giant tarps referred to as “curtains” that can be drawn to control the environment that the animals are subjected to. After transport the curtains are opened (if previously closed) and trailers are parked alongside banks of fans to blow fresh air through the crates and reduce temperature around the birds.

Sometimes birds are loaded into modular drawers (Figure 24) which are similar to crates but are already joined to make one transport unit instead of having to stack the crates which results in faster loading times.

Figure 24. Broiler chickens loaded into modular drawers for transport (Dam et al., 2016).

5.1 Microclimate

Poultry have relatively high body temperatures, rapid heart rates, and narrow thermal tolerance zones. Birds also do not have sweat glands and instead have to rely on panting (also known as gular fluttering) to cool themselves. Chickens have a normal body temperature that ranges from 40.6°C to 43.0°C (105.1°F to 109.4°F) and have a resting heart rate of 250-300 bpm

(Merck Veterinary Manual, 2008). Poultry, like the other previously discussed species, are better equipped to tolerate cold stress rather than heat stress. The body temperature of a chicken can drop to 22.8°C (73°F) before death but can only withstand body temperatures of 45°C to 47°C (113°F to 117°F). The optimum comfort temperature is 21°C to 24°C (70°F to 75.2°F) for poultry and the upper critical temperature range from 29°C to 32°C (84.2°F to 89.6°F; Pereira and Naas, 2008).

Even though poultry trailers do not have the same wall and punch hole structure style as that of pot belly and straight deck trailers, the airflow is still similar in that air enters at the rear of the trailer and exits toward the nose. Airflow can be altered more easily in poultry trailers, however, for this style has curtains that can be drawn or opened to alter the environment instead of having to place boards or punch hole covers to combat poor weather conditions (Figure 25).

Figure 25. Poultry trailer with front bulkhead and drawn curtains (Photo Credit: Redwood Plastics).

Even with curtain manipulation, airflow is still quite variable around the crates. Weeks et al. (1997) measured the airflow around and through the cages and found that air velocities ranged from 0.9 to 2.4 m/s with gusts reaching upwards of 6 m/s. An experiment was conducted with roof mounted inlet fans and found more consistent airflow (roughly 0.3 m/s to 1.0 m/s) that kept the trailer within safe temperature ranges (Weeks et al., 1997). Commercial load ventilation requirements range from 100 m^3/hr to 600 m^3/hr within the European Union but Kettlewell et al. (2000) proposed that instead of basing ventilation on a per load basis, to take the body weight of the chickens into account and recommended that for external temperatures of 20°C or less, that 2.2 m^3 /hr/ kg chicken body weight would be a better ventilation guideline. Another issue to consider is that of crate heights and porosity of crates. Wichman et al. (2012) found that turkeys transported in short crates (40 cm in height) panted more than turkeys transported in tall crates (55 cm in height).

Birds that do not survive the transport process, i.e., dead on arrival (DOA), are not an uncommon occurrence. Weeks et al. (2012) conducted a study using end-of-lay (cull) hens to determine the number of DOA birds after varying transport lengths (up to 500 km) and reported that only 7% of the loads had no DOA birds 40% of the DOA birds could be caused by heat stress (Bayliss and Hinton, 1990). Warriss et al. (2005) found that mortality increased when ambient temperatures rose above 17°C (62.6°F) and increased sevenfold when above 23°C (73.4°F).

Chicks and poults are susceptible to heat and cold stress and are thus transported in enclosed trucks with environmental temperature from 21°C (70°F) to 35°C (95°F) and relative humidity from 50% to 65%. These trucks also use the rule of 0.71 m^3/min of fresh air per 1,000 chicks or poults but not such alterations are taken with adult chickens. Broiler chickens are simply transported in crates that are stacked on top of each other onto a pallet and rolled or mechanically lifted onto a truck that may or may not be enclosed by curtains (tarps) during transport. One consistent part of the process is lighting is kept dim if possible to keep birds calm especially during handling processes.

5.2 Loading Density

Crates are used to transport birds instead of compartments within a trailer. Several birds are loaded into crates of various dimensions where the crates are then stacked and loaded onto the trailer. Weight limits still have to be observed but now instead of dealing with loading density as an issue of area, volume allowances are evaluated.

Birds transported in lower stocking densities had lower glucose levels after transport meaning that the animals had too much room to move about and extended extra energy increasing the likelihood of injuring themselves and the other birds that occupied the crate. Increased heterophil:lumphocyte ratios were reported by Bedanova et al. (2006) after examining the difference in crate loading densities when comparing 105 cm^2/kg to 115 cm^2/kg and confirmed that higher loading densities can increase the stress of the animal as well as extremely low loading densities. Some have reported higher numbers of deaths due to injuries during 8 hours of transport with hens that had a loading density of less than 207 cm^2/kg. Other indicators of stress used to measure animal welfare include increased levels of glucagon, lactate, plasma corticosterone, heterophil: lymphocyte ratios (Freeman et al., 1984; Mitchell et al., 1992). Several studies were conducted from all over the world to assess the issue of DOA birds. Based on these surveys, an estimate of 0.2% of the world’s poultry is unusable just from the transport from farm to processing facility (Weeks, 2014).

The number of chickens or turkeys loaded into each shipping container (crate or modular drawer) is determined by the Code of Practice and takes into account the age and weight of the birds, the container size, and weather conditions. Tables 1 and 2 are adapted from the recommend Codes of Practice to ensure proper loading density for three common cage sizes used for birds in both hot and cold weather (NFACC, 2017).

Table 1. Broiler chicken transport loading density (NFACC, 2017).

Number of Broiler Chickens per Crate/Modular Drawer: Loading Density for Hot and Cold Weather						
Crate Dimensions	0.71m x 1.12m		1.12m x 1.19m		0.58 m x 0.86m	
Crate Area	$0.79m^2$		$1.3m^2$		$0.5m^2$	
Weight (kg)	63 kg/m^2	54kg/m^2	63 kg/m^2	54kg/m^2	63 kg/m^2	54kg/m^2
1.75	28	24	48	41	18	15
2.00	25	21	42	36	16	14
2.25	22	19	37	32	14	12
2.50	20	17	34	29	13	11
2.80	18	15	30	26	11	10
3.50	14	12	24	21	9	8

Chickens and turkeys can safely be loaded at higher loading densities during colder weather (63 kg/m^2 and 98 kg/m^2, respectively and lower densities during warm weather (54 kg/m^2 and 83 kg/m^2, respectively). The cold weather loading densities are represented by the blue columns while the warm weather conditions are listed in the red columns of Table 1 and 2.

Heat stress can be minimized by being conscious of load times and temperatures, loading density of birds in cages, loading damp birds last, and minimizing transport times. Loading densities should be reduced by 15% to 20% during extreme heat to allow for more airflow around the birds and less heat generation (NFACC, 2017).

Table 2. Turkey transport loading density (NFACC, 2017).

Number of Turkeys per Crate/Modular Drawer: Loading Density for Hot and Cold Weather				
Crate Dimensions	1.14m x 1.14m		1.14m x 0.94m	
Crate Area	$1.32m^2$		$1.09m^2$	
Weight (kg)	$98kg/m^2$	$83kg/m^2$	$98kg/m^2$	$83kg/m^2$
5.29	24	21	20	17
6.5	20	17	16	14
7.87	16	14	14	11
10	13	11	11	9
15	9	7	7	6
20	6	5	5	5

Birds have the potential to suffocate if the weather tarps are left in place during stationary phases and sometimes while moving, even if weather conditions call for their use (Mitchell et al., 1992; Burlinguette et al., 2012). Lack of oxygen is characterized by gasping, constant neck stretching, and purple combs and wattles. Openings in the curtains especially towards the very back and the very front of the trailer can help reduce the likelihood of this issue but are not always available based on curtain type. While in lairage, the trucks drive underneath a shade unit where there are multiple fans set up to blow air through the bird cages, introducing fresh air into the bird's surroundings, removing heat and moisture generated by the animals, thus cooling them and reducing stress.

Even though poultry trailers with open sides are not fully contained like pot belly or straight deck trailers, the air still enters the back end of the trailer and moves up the trailer and out the nose, with the exception being that the airflow in this movement stays lower and closer to the floor of the trailer, resulting in unequal ventilation (Baker et al., 1996; Hoxey et al., 1996). Studies conducted in Canada reported that during cool ambient conditions of 9.8°C (49.6°F) with the roof vents and side curtains open, temperatures around the animals ranged from 10.3°C to 16.7°C (50.5°F to 62.1°F); however, when temperatures became drastically cold (-22.7°C or -8.9°F) temperatures varied from -20.7°C to 21.7°C (-5.3°F to 71.1 F) with over 50% of the birds subjected to below 0°C (32°F) environments throughout the majority of the journey, even with the implementation of curtains (Burlinguette et al., 2012).

Some researchers reported both hyperthermic and hypothermic birds coming out of different areas of the same curtained truck in Canadian wintertime showing a lack of trailer homogeny (Knezacek et al., 2010). Vosmerova et al. (2010) found that cold weather conditions at 0°C (32°F) externally could yield a high of 18°C (64.4°F) internal trailer temperatures but still have cold stress results. This is partially due to the lack of consistent environment, resulting in birds in different areas of the trailer being exposed to different temperatures falling within that range.

The thermal neutral zone of poultry is more narrow than that of pigs and cattle. Broiler chicken mortality greatly increased when external temperatures were above 15°C (59°F) or at or below 5°C (41°F; Nijdam et al., 2004). Turkeys in Canada experienced cyanosis damage (frostbite) when outdoor temperatures dropped below zero on an 8 hour journey (Mallia et al., 2000).

5.3 Duration

The longer birds are transported, the more severe the fatigue and overall stress the animals endure. Fatigue symptoms in chickens are directly correlated with depleted glycogen stores and dehydration (Warriss et al., 1988). Chickens are transported relatively short distances from farm to slaughter facility when compared to the distances cattle, pigs, and other livestock travel. Transport aspects such as temperature and loading density have been deemed to be more pressing issues in poultry welfare than time spent in transport. This results in fewer studies done to determine transport duration effects on the animals.

Even though fewer studies have been conducted to determine the effects of transport time it is known that birds quickly lose body weight under stressful conditions. After 4 to 6 hours of fasting, body weight loss occurs at a rate of 0.2%-0.5% per hour (Veerkamp, 1986) and Delezie et al. (2007) found that chicken that were not fed for 13 hours before transport, meaning that there was no food stored in the crop or digestive tract of the animal, could lose 5% of pretransport body weight. Food and water deprivation for a 24-hour period resulted in a 10% decrease in live weight of which 41% was carcass weight loss (Knowles et al., 1995). Warriss et al. (1999) found that birds that are transported longer than 4 hours have an 80% increase in the likelihood of death.

5.4 Behavior

Birds are handled as few times as possible throughout their lives. Workers are often instructed to move slowly and carefully through the barns so as to not cause the birds to pile on top of each other, crushing and/or suffocating those on the bottom. Certain stress responses of chickens were greatly reduced by gentle handling practices (Jones, 1992). This general behavior shows that there are several complications after animals are loaded into crates and are subjected to the stress of moving transport. Biological markers such as plasma corticosterone increases under stress (Kannan and Mench, 1997). Kolb and Seehawer (2001) suggested that adding ascorbic acid (vitamin C) into the drinking water could potentially decrease stress levels, especially during transport.

Vibration has been previously addressed as a factor affecting animal welfare (Gebresenbet et al., 2011). Most poultry transport vehicles give off a frequency of 1-2 Hz with periodic peaks of 10 Hz (Scott, 1994). Randall et al. (1997) found that resonant frequencies of the birds were 4 Hz when standing and almost 15 Hz when laying down are the most adversely influenced by frequencies of 1-5 Hz. Stressed poultry can exhibit the same undesirable meat quality that stressed pigs can in that they can also have PSE meat (pale, soft, exudative) characteristics and can be reduced by cooling the animals by altering loading densities, increasing airflow, or even using water sprinklers on heat stressed birds (Guarnieri et al., 2004) but currently there is not corrective measure for vibration stress.

Poultry will huddle closely together when frightened by speed, bright light, strangers, unusual or loud sounds, also during periods of low ambient temperatures and solar radiation, when wind speeds are high, with precipitation, and when transport conditions are dark, either by the time of day or by the drawing of curtains. In short, birds are normally huddled together during transport. This can increase the stress that the animals endure by heat exchange and also physical injuries. Jacobs (2016) conducted a study that showed preslaughter transport resulted in 5.3% body weight loss (shrink), 1.4% prevalence in leg bruises and 3.7% breast or wing bruises. Other issues observed were skin lesions, panting, and wing and leg fractures (most likely from catching to be placed into transport crates). More bruising (4.14% as compared to 2.44%) was seen when truck curtains were open and similar results were seen when birds were transported at night instead of in the morning or during the day (4.14%, 2.87% and 2.53% respectively).

Heat and cold stress is as much of an issue during poultry transport as it is for any other livestock. Some argue that is more detrimental for chickens and turkeys for the animals are more densely packed into the transport space than other livestock. Birds also have a higher body temperature and a narrower thermal neutral zone making them more susceptible to heat and cold stress. Signs of heat stress include panting or open mouth breathing and red flushed while cold stress manifests itself as shivering, puffed feathers, blue combs.

5.5 Research and Development Needs

Poultry are the most sensitive animals evaluated within this report regarding transportation stress. This is in part due to the way that the fully-grown birds are transported. Chicks are transported in completely enclosed trailers that are environmentally controlled while adults transport is either completely exposed to the external environment or completely enclosed with no temperature regulation. Exploration of alternative methods such as mesh and/or vented curtains as well as the implementation of fans would benefit the animals. With enclosed trailer popularity increasing, there could be a shift to transport birds in similar designs. This shift would require further research to find a balance between animal wellbeing and economic feasibility.

Other factors such as crate height and an evaluation of loading density based on distance and duration of journey instead of only temperature would also contribute to animal welfare evaluations.

5.6 Conclusion

Live and carcass weight are primary indicators of animal profitability, regardless of species. Birds are no exception and are more susceptible to profit drops due to weight changes for, of all the species discussed, these animals have the largest surface area to volume ratio. Poultry product requires animal numbers have to be exceptionally large with faster life cycles, and overall improved product recovery in order to make up for what little meat can be harvested per animal.

Birds are raised in completely contained environments with as few stressors as possible. This includes an overall lack of human interactions for the majority of their lives. This changes when it comes time to be transported where the birds are herded and physically handled before being placed in crates or drawer modules and subjected to one of the most stressful environments of their lives. Birds are placed in transport containers based on the weight and type of the bird and the size of the storage container. They are placed in poultry trailers that can either be open to the elements or can be completely closed off with transport curtains which can result in heat or cold stress depending on the environment, and can potentially result in suffocation if not monitored. The birds are transported for a length of time, losing 0.2% to 0.5% of body weight for every hour of transport (Veerkamp, 1986) to slaughter facilities where the trucks are parked in front banks of fans to increase ventilation through the trailers. This allows the slaughter facility to pace out processing times without severe consequences if unable to unload the birds immediately after arrival and the fans are also there to calm the birds before being handled again during offloading and final processing.

There are many aspects to poultry transport that can be improved to reduce animal stress. Increases in regulations and trailer modifications that are slow taking place in other regions for different livestock species may instigate further changes in poultry production to reduce the number of chicken and turkey mortalities during transport.

Chapter 6 - Summary and Conclusion

Animal transport is a necessary event for livestock production but can be detrimental to the overall health and well-being of the animal. Transport involves the handling, moving, and loading of the animals, the entire time the animals are within the transport trailer, unloading processes, and wait time in lairage. This can be a relatively short stint of time but can take many hours or even days depending on the situation. Individual countries make their own transport laws as to how long the animals can be inside the vehicles and most regulate weight of load instead of head numbers.

The United States has one of the shortest time restrictions with the animals only being allowed to remain in transport for 28 hours, whereas Canada allows 48 hours unless the destination can be reached with another 4 hours allowance in which case the truck and trailer can proceed. After these times limits have been reached, the truck must stop, offload the animals, and allow them access to food and water for a minimum of 5 hours before reloading and continuing the journey. The European Union allows for 30 hours of transport but requires more stringent regulations to internal trailer environment conditions and monitoring systems. These time regulations could undergo changes after the new electronic logging device law is enacted. There are not only regulations as to how long the animals can remain on the truck but there are limitations that the trucks can be waiting to offload animals at slaughter facilities.

Commercial livestock trailers have been altered very little in the last half century. Height and width requirement must be strictly followed but lengths can vary based on the manufacturer and buyer. Airflow within the trailers runs in a general antiparallel flow to the external airflow. Air is taken in at the rear of the trailer, moves up the length of the trailer, and exits through the nose towards the truck.

There are three main opening configurations that are seen with livestock trailers with these being punch hole, duffy, and slat. Pot belly trailers are very common in hauling cattle and pigs due to the dropped middle section that allows for improved space utilization. Straight deck trailers are more common in hauling short animals such as pigs. Poultry trailer are specifically for poultry where the birds are loaded into crates or modular drawers that are then loaded onto the trailers like pallets. Enclosed trailers are very popular in the European Union and have started to enter the market within Canada, which could potentially change how adult poultry is transported.

Cattle are transported the most throughout their lifetimes when comparing the three livestock types reviewed in this paper. All the animals reviewed are homeotherms but environmental aspects reduce the efficiency of their homeostatic processes. Market weight cattle are more susceptible to heat stress rather than cold stress and the presence of high humidity intensifies heat stress. The Temperature-Humidity Index (THI) is a formulated equation that has been converted into a chart also known as the Livestock Weather Safety Index (LWSI) to determine how severe the climate is for the animals by relating temperature and humidity.

Modifications can be made to better control the airflow within the trailers. Modified air scoops that were retrofitted to trailers were used to increase air flow but did not see enough improvement to be economically feasible at the time. Boarding is another microclimate alteration that is done quite frequently. Boarding is the practice of covering the holes of the trailer to reduce the effects of cold stress within the trailer. This is done mainly in northern parts of the United States and Canada, especially when hauling calves and hogs. These modifications are helpful when applied to moving trailers but temperatures can reach dangerous levels even when stationary.

Loading density is how much space the animal has within the trailer. Equations for loading density have been developed to ensure that the animals have enough space to ensure an acceptable state of wellbeing. Different densities also affect microclimate and airflow around the animals.

Duration is limited within the United States and Canada by transport time restrictions but the time periods are not short enough to ensure maximum welfare by the end of the trip for it would not be economically feasible to do so. One researcher found that the likelihood of cattle mortality doubled from 20 hours to 30 hours and increased by a factor of seven after 30 hours of transport and another reported that the average transport time within the United States was 15.9 hours. Similar reports of increasing mortality with lengthening transport times were reported for swine and poultry transport as well.

All animals have a thermal comfort zone where the animal is able to achieve maximum performance if lacking other stressors. The thermal neutral zone encases the thermal comfort zone and means that the animal is not extending extra energy to maintain safe internal temperatures, anything outside this zone results in either heat or cold stress. When cattle are stressed there is an increase in shrink, meaning body weight loss, and an increase in "dark cutting" beef which drastically decreases profits.

Swine are hauled in a variety of their trailers due to their size. The swine industry sees drastic profit losses due to DOA animals. This is in part due to the smaller thermal neutral zones of pigs as compared to cattle. Some trailers are fitted with fans and/or sprinkler systems in efforts to reduce the stress that the pigs endure. Boarding is a common practice in pig transport to reduce the effects of cold stress. Loading densities were found to vary from 0.47 m^2 per animal to 0.30 m^2 per animal and resulted in a 7.55- fold increase in death when comparing the minimum density to the maximum. As pigs become more stressed, the incidence of PSE meat increase, thus linking animal welfare to carcass quality.

Poultry are the least transported animal type of the three observed with the highest number of head processed each year. Chickens and turkeys are transported in crates or modular drawers where they are then loaded on a poultry trailer that locks these stacked containers into place where they are transported to processing facilities and are parked in front of fans to reduce stress while waiting to offload. The Codes of Practice utilize common crate size and general bird weight to create easy charts to encourage facilities to more closely monitor loading practices. Chickens are very susceptible to heat and cold stress to the point were loading density variations and curtains to enclose the trailers during transport are used to help control temperatures around the birds and found that chickens can lose body weight at a rate of 0.2% to 0.5% per hour of transport.

6.1 Recommendations for Future Work

Microclimate during transport has been deemed to be a major contributor to animal welfare. Livestock trailers have very similar internal air flow patterns but these patterns have not been conducted in relation to the size of the animals being hauled and the loading density of each compartment. Starting with the natural ventilation of trailers for various species would be beneficial but evaluating facilitated airflow such as the air scoops and mechanical ventilation such as the fans is needed as well. There is also the evaluation of external trailer cooling systems such as fan banks at slaughter facilities for different species to be conducted.

The factors addressed in this report have been evaluated for many different species and ages within that species, however, they have rarely been done to determine the effects one has on the others. Each of these factors should be evaluated while all else is held constant to determine relationships to improve transportation practices. Research conducted with different loading densities in different temperatures for different durations would allow for companies to better understand how to transport their animals to ensure overall welfare of the livestock and maintain the value of the animal.

References

Appleby, M.C., Cussen, C., Garces, L., Lambert, L.A., and Turner, J. 2008. Long distance transport and welfare of farm animals. CABI Publishing, Wallingford, UK.

Averos, X., Gosalvez, L.F., Brown, S.N., Warriss, P.D., and Knowles, T.G. 2010. Factors affecting the mortality of weaned piglets during commercial transport between farms. Veterinary Record 167: 815-819.

Averos, X., Knowles, T.G, Brown, S.N., Warriss, P.D., and Gosalvez, L.F. 2008. Factors affecting the mortality of pigs being transported to slaughter. Veterinary Record 163: 386-390.

Baker, C.J., Dalley, S., Yang, X., Kettlewell, P., and Hoxey, R. 1996. An investigation of the aerodynamic and ventilation characteristics of poultry transport vehicles. 2. Wind tunnel experiments. Journal of Agricultural Engineering Research 65:97-113.

Barton Gade, P. and Christensen, L. 1998. Effect of different stocking densities during transport on welfare and meat quality in Danish slaughter pigs. Meat Science 48: 237–247.

Bayliss, P.A. and Hinton, M.H. 1990. Transportation of poultry with special reference to mortality rates. Applied Animal Behaviour Science 28:93-118.

Bedanova, I., Voslarova, E., Vecerek., V., Pistekova, V., and Chloupek, P. 2006. Effects of reduction in floor space during crating on haematological indices in broilers. Berliner und Munchener Tierarztliche Wochenschrift 119:17-21.

Bosona, T., and Gebresenbet, G. 2013. Food traceability as an integral part of logistics management in food and agricultural supply chain. Food control 33:32-48.

Bradshaw, R.H. and Hall, S.J.G. 1996. Incidence of travel sickness in pigs. Veterinary Record 139:503.

Bradshaw, R.H., Parrott, R.F., Forsling, M.L., Goode, J.A., Lloyd, D.M., Rodway, R.G. and Broom, D.M. 1996. Stress and travel sickness in pigs: effects of road transport on plasma concentrations of cortisol, beta-endorphin and lysine vasopressin. Animal Science 63:507-516.

Broom, D. M. 2003. Causes of poor welfare in large animals during transport. Veterinary Research Communications 27:515-518.

Broom, D. M. 2007. Causes of poor welfare and welfare assessment during handling and transport. Livestock Handling and Transport 3:30-43.

Broom, D.M. and Johnson, K.G. 1993. Stress and Animal Welfare. Chapman and Hall, London.

Brown-Brandl, T. M., Nienaber, J. A., Xin, H., and Gates, R. S. 2004. A literature review of swine heat production. Transactions of the ASAE 47: 259.

Brown-Brandl, T. M., Nienaber, J.A., and Eigenberg, R.A. 2005a. Heat stress risk factors for feedlot heifers. Pages 559-565 in Proc. Seventh International Livestock Environment Symposium (American Society of Agricultural Engineers), St. Joseph, MI.

Brown-Brandl, T.M., Eigenberg, R.A., Nienaber, J.A., and Hahn, G.L. 2005b. Dynamic response indicators of heat stress in shaded and non-shaded feedlot cattle: Part I. Analysis of indicators. Journal of Biosystems Engineering 90:451-462.

Brumm, M., Richert, B., Marchant-Forde, J., and Marchant-Forde, R. 2005. Out-of-feed Events in Grow-finish Pigs: Causes and Consequences. Nebraska Swine Report 1-1-2005 Paper 24, University of Nebraska USDA. Oct. 5, 2017. http://digitalcommons.unll.edu/coopext _swine /24.

Bryan, M. 2013. Trailer micro-climate during long-distance transport of finished beef cattle for the summer months in North America. Master of Science Thesis. University of Saskatchewan, Canada.

Bulitta, F. S. 2015. Effects of handling on animals welfare during transport and marketing. PhD Dissertation. Swedish University of Agricultural Science.

Burlinguette, N.A., Strawford, M.L., Watts, J.M., Classen, H.L., Shand, P.J., and Crowe, T.C. 2012. Broiler trailer thermal conditions during cold climate transport. Canadian Journal of Animal Science 92:109-122.

Camp, T. H., Stevens, D. G., Stermer, R. A., and Anthony, J. P. 1981. Transit factors affecting shrink, shipping fever and subsequent performance of feeder calves. Journal of Animal Science 52: 1219-1224.

CARC (Canadian Agri-food Research Council). 2001. Recommended codes of practice for the care and handling of farm animals-Transportation. Accessed November 15, 2016. http://www.nfacc.ca/pdf/english/ Transportation2001.pdf

CEC. 2005. Regulation No 1/2005 relative to the protection of animals during transportation. The Council of the European Communities. December 22, 2004. Amends Directives 64/432/EEC and 93/119/EC and Regulation (EC) No. 1255/97.

Chai, J. Xiong, Q., Zhang, C.X., Miao, W., Li, F.E., Zheng, R., Peng, J., and Jiang, S.W. 2010. Effect of pre-slaughter transport plant on blood constituents and meat quality in halothane genotype of NN Large White x Landrace pigs. Livestock Science 27-211-217.

Cockram, M. S. 2007. Criteria and potential reasons for maximum journey times for farm animals destined for slaughter. Applied Animal Behaviour Science 106:234-243.

Coffey, K.P., Coblentz, W.K., Humphry, J.B., and Brazle. F.K. 2001. Review: Basic principles and economics of transportation shrink in beef cattle. Professional Animal Scientist 17:247-255.

Cooke, R.F., Guarnieri Filho, T.A., Cappellozza, B.I., and Bohnert. D.W. 2013. Rest stops during road transport: Impacts on performance and acute-phase protein responses of feeder cattle. Journal of Animal Science 91:5448-5454.

CPEPC. 2017. Poultry Handling and Transportation Manual. Poultry Service Association.

Crum, M. R., and Morrow, P. C. 2002. The influence of carrier scheduling practices on truck driver fatigue. Transportation Journal 42:20-41.

Curtis, S. E. 1983. Environmental management in animal agriculture. Iowa State University Press, Ames.

Dadgar, S. 2010. Effect of cold stress during transportation on post-mortem metabolism and chicken meat quality. PhD Dissertation, University of Saskatchewan, Canada.

Dalla Costa, O.A., Faucitano, L., Coldebella, A., Ludke, J.V., Peloso, J.V., Dalla Roza, D., and Paranhos da Costa, M.J.R. 2007. Effects of the season of the year, truck type, and location on truck on skin bruises and meat quality in pigs. Livestock Science 107, 29-36

Dam, A., Ward, D., McDonald, S., and Bordin, A. 2016. Transition on the Ontario Broiler Chicken Farm to Modular Loading. Oct. 8, 2017 http://www.omafra.gov.on.ca/english/engineer/facts/16-037.htm.

Dee, S., Torremorell, M., Thompson, B., Deen, J., and Pijoan, C. 2005. An evaluation of thermo-assisted drying and decontamination for the elimination of porcine reproductive and respiratory syndrome virus from contaminated livestock transport vehicles. Canadian Journal of Veterinary Research 69:58-63.

Delezie, E., Swennen, Q., Buyse, J., and Decuypere, E. 2007. The effect of feed withdrawal and crating density in transit on metabolism and meat quality of broilers at slaughter weight. Poultry Science 86:1414-1423.

Dewey, C., Haley, C., Widowski, T., and Friendship, R. 2004. Factors associated with in-transit losses. Pages 51-54 In Proceedings of the London swine conference, London, UK.

EFSA. 2004. Opinion of the scientific panel on animal health and welfare on a request from the commission related to the standards for the microclimate inside animal road transport vehicles. The EFSA Journal 122: 1-25.

Eldridge, G. A., and Winfield, C. G. 1988. The behaviour and bruising of cattle during transport at different space allowances. Animal Production Science 28:695-698.

Ellis, M., and Ritter, M. 2006. Management practices and meat quality. Pages 18-21 In Proceedings of the 59th American Meat Science Association Reciprocal Meat Conference, Champaign-Urbana, IL.

Ellis, M., Wang, X., Funk, T., Wolter, B., Murphy, C., Lenkaitis, A., and Pilcher, C. 2010. Impact of trailer design factors on conditions during transport. Pages 18-21 In Proceedings of the 2010 Allen D. Leman Swine Conference, St. Paul, MN.

EU. 2005. European Union Council Regulation No. 1/2005 of 22 December 2004 on the protection of animals during transport and related operations and amending Directives 64/432/EEC and 93/119/EC and Regulation (EC) No. 1255/97. Official Journal of the European Union L3/1 (5.1.2005), 1–44. http://europa.eu/legislation_summaries/food_safety/animals_welfare/f83007_en.htm.

European Commission. 2001. Report from the Commission to the council and the European Parliament on the application on the different ventilation systems for Animal transport from road journeys exceeding eight hours. Scientific Committee on Animal Health and Welfare. Brussels. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52001DC0197.

FAWC. 1993. Second Report on Priorities for Research and Development in Farm Animal welfare. MAFF Publishing, Tolworth, London, UK.

Fazio, E., and Ferlazzo, A. 2003. Evaluation of stress during transport. Veterinary Research Communications 27:519-524.

Ferguson, D. M., and Warner, R.D. 2008. Have we underestimated the impact of pre-slaughter stress on meat quality in ruminants? Meat Science 80:12-19.

Fike, K., and Spire, M.F. 2006. Transportation of cattle. Veterinary Clinic. North American: Food Animal Practice 22:305-320.

Finch, V. A. 1986. Body temperature in beef cattle: its control and relevance to production in the tropics. Journal of Animal Science 62:531-542.

Fiore, G., Hofherr, J., Natale, F., Mainetti, S., and Ruotolo, E. 2012. Transport temperatures observed during the commercial transportation of animals. Veterinaria Italiana 48:15-29.

Fisher, A. D., Colditz, I.G., Lee, C., and Ferguson, D.M. 2009. The influence of land transport on animal welfare in extensive farming systems. Journal of Veterinary Behavior: Clinical Applications and Research 4:157-162.

Fitzgerald, R., Stalder, K., Matthews, N., Schultz-Kaster, C., and Johnson, A. 2009. Factors associated with fatigued, injured, and dead pig frequency during transport and lairage at a commercial abattoir. Journal of Animal Science 87:1156-1166.

Flint, H. 2013. Load characteristics and the behaviour of beef cattle unloaded for feed, water and rest during long distance transportation in Canada. Master of Science Thesis. University of Guelph, Ontario.

Flint, H. E., Schwartzkopf-Genswein, K. S., Bateman, K.G., and Haley, D.B. 2014. Characteristics of loads of cattle stopping for feed, water and rest during long-distance transport in Canada. Animal 4:62-81.

FMCSA. 2017a. Federal Motor Carrier Safety Administration: Summary of Hours of Service Regulations. https://www.fmcsa.dot.gov/regulations/hours-service/summary-hours-service-regulations.

FMSCA. 2017b. Federal Motor Carrier Safety Administration: ELD Hours of Service (HOS) and Agricultural Exemptions. https://www.fmcsa.dot.gov/hours-service/elds/eld-hours-service-hos-and-agriculture-exemptions.

Fraser, A.F., and Broom, D.M. 1990. Farm Animal Behaviour and Welfare. Bailliere Tindall, London.

Freeman, B.M., Kettlewell, P.J., Manning, A.C.C., and Berry, P.S. 1984. The stress of transportation for broilers. Veterinary Record 114:286-287.

Frese, D. A., Reinhardt, C.D., Bartle, S.J., Rethorst, D.N., Hutcheson, J.P., Nichols, T.W., Depenbusch, B.E., Corrigan, M.E., and Thomson, D.U. 2016. Cattle handling technique can induce fatigued cattle syndrome in cattle not fed a beta adrenergic agonist. Journal of Animal Science 94:581-591.

Friend, T. 2006. Improving Ventilation in Commercial Cattle Trailers to Reduce Stress and Disease. Texas Cattle Feeders Association. https://www.tcfa.org/assets/media/pdfs/research/100_improving_ventilation_in_commercial_cattle_trailers_to_reduce_stress_and_disease.pdf

Galyean, M. L., Lee, R.W., and Hubbert, M.E. 1981. Influence of fasting and transit on ruminal and blood metabolites in beef steers. Journal of Animal Science 53:7-18.

Gaughan, J. B., Holt, S.M., Hahn, G. L., Mader, T.L., and Eigenberg, R. 2000. Respiration rate-is it a good measure of heat stress in cattle? Asian Australian Journal of Animal Science 13:329-332.

Gaughan, J. B., Mader, T. L., Holt, S.M., Hahn G.L., and Young, B.A. 2002. Review of current assessment of cattle and microclimate during periods of high heat load. Animal Production Australia 24:77-80.

Gebresenbet, G., and Eriksson, B. 1998. Effects of transport and handling on animal welfare, meat quality and environment with special emphasis on tied cows. Department of Energy and Technology 233:45

Gebresenbet, G., Aradom, S., Bulitta, F.S., and Hjerpe, E. 2011. Vibration levels and frequencies on vehicle and animals during transport. Biosystems Engineering 110:10-19.

Giguere, N. M. 2006. Increasing ventilation in commercial cattle liners to decrease shrink, morbidity, and mortality. Master of Science Thesis. Texas A & M University.

Gilkeson, C. A., Thompson, H.M., Wilson, M.C., and Gaskell, P.H. 2016. Quantifying passive ventilation within small livestock trailers using Computational Fluid Dynamics. Computer and Electronics in Agricultural 124:84-99.

Goding, H., and Raub, J. A. 1918. The 28-hour law regulating the interstate transportation of livestock. Accessed Feb. 13, 2016. https://www.nal.usda.gov/sites/default/files/28hour

1918_0.pdf

Goldhawk, C. 2014. Microclimate During Beef Cattle Transport: Effects of Transportation Management and Relationship to Indicators of Animal Welfare. PhD Dissertation. University of Calgary, Alberta.

Goldhawk, C., Janzen, E., González, L.A., Crowe, T., Kastelic, J., Kehler, C., Siemens, M., Ominski, K., Pajor, E., and Schwartzkopf-Genswein, K.S. 2015. Trailer temperature and humidity during winter transport of cattle in Canada and evaluation of indicators used to assess the welfare of cull beef cows before and after transport. Journal of Animal Science 93:3639-3653.

González, L. A., Schwartzkopf-Genswein, K.S., Bryan, M., Silasi, R., and Brown, F. 2012a. Space allowance during commercial long distance transport of cattle in North America. Journal of Animal Science 90:3618-3629.

González, L. A., Schwartzkopf-Genswein, K.S., Bryan, M., Silasi, R., and Brown, F. 2012b. Factors affecting body weight loss during commercial long haul transport of cattle in North America. Journal of Animal Science 90:3630-3639.

González, L. A., Schwartzkopf-Genswein, K.S., Bryan, M., Silasi, R., and Brown, F. 2012c. Benchmarking study of industry practices during commercial long haul transport of cattle in Alberta Canadian Journal of Animal Science 90:3606-3617.

González, L. A., Schwartzkopf-Genswein, K.S., Bryan, M., Silasi, R., and Brown, F. 2012d. Relationships between transport conditions and welfare outcomes during commercial long haul transport of cattle in North America. Journal of Animal Science 90:3640-3651.

Gosalvez, L.F., Averos, X., Valdelvira, J.J., and Herranz, A. 2006. Influence of season, distance and mixed loads on the physical and carcass integrity of pigs transported to slaughters. Meat Science 73: 553-558.

Goumon, S., Brown, J.A., Faucitano, L., Bergeron, R., Widowski, T.M., Crowe, T., and Gonyou, H.W. 2012. Effects of season and transport duration on behaviour, heart rate and body temperature of market weight pigs. Pages 18-21 In Proc. Animal Transportation Association (ATA) 38th Annual Meeting, Vancouver, BC.

Grandin, T. 1981. Livestock Trucking Guide. Livestock Conservation Institute, Madison, Wisconsin.

Grandin, T. 1997. Assessment of stress during handling and transport. Journal Animal Science 75:249-257.

Grandin, T. 2001. Cattle vocalizations are associated with handling and equipment problems at beef slaughter plants. Applied Animal Behavior Science 71:191-201.

Grandin, T. 2010. Recommended Animal Handling Guidelines and Audit Guide: A Systematic Approach to Animal Welfare. Washington, D.C: American Meat Institute Foundation. ((Accessed June 15, 2016). http://www.animalhandling.org/ht/a/GetDocumentAction/i/63215)

Grandin, T. 2012. Recommended Animal Handling Guidelines and Audit Guide: A Systematic Approach to Animal Welfare. Washington, D.C: American Meat Institute Foundation ((accessed March 1, 2016) http://www.animalhandling.org)

Grandin, T. 2014. Livestock Handling and Transport: Theories and Applications. 4th ed. CABI Publishing, Wallingford, UK.

Greer, T. 2013. Transport of finished heifers in warm ambient temperatures: An assessment of trailer microclimate and animal well-being for two transport distances. master of science thesis. University of Saskatchewan, Canada.

Guarnieri, P.D., Soares, A.L., Olivio, R., Schneider, J.P., Macedo, R.M., Ida, E.I., and Shimokomaki, M. 2004. Preslaughter handling with water shower inhibits PSE (pale, soft, exudative) broiler breast meat in a commercial plant. Biochemical and ultrastructural observations. Journal of Food Biochemistry 28:269-277.

Guise, H.J. 1987. Moving pigs from farm to factory. Pig International, Dec. 1987:8-12.

Guise, H.J., and Penny, R.H. 1989. Factors influencing the welfare and carcass meat quality of pigs. Animal Production 49: 511-515.

Guise, H.J., Hunter, E.J., Baynes, P.J., Wigglesworth, P.J., Riches, H.L., and Penny, R.H.C. 1996. Observations of the behaviour of slaughter-weight pigs during transport. The Pig Journal 38:19-29.

Haag, H. M. 1945. Transportation of livestock by motor truck to the Kansas City market. https://www.ksre.k-state.edu/historicpublications/pubs/SB324.PDF.

Hahn, G. L. 1999. Dynamic responses of cattle to thermal heat loads. Journal of Animal Science 77:11-20.

Haley, C. Dewey, C.E., Widowski, T., and Friendship, R. 2008. Association between in-transit loss, internal trailer temperature, and distance traveled by Ontario market hogs. Canadian Journal Veterinary Research 72:385-389.

Hall, S. J., and Bradshaw, R.H. 1998. Welfare aspects of the transport by road of sheep and pigs. Journal of Applied Animal Welfare Science 1:235-254.

Hartung, J., and Springorum, A.C. 2009. Animal welfare and transport. Welfare of production animals: Assessment and management of risks. Pages 149-168, Wageningen Academic Publishers, Wageningen, NT.

Hicks, B. 2012. Beef Cattle Research Update. Oklahoma Panhandle Research and Extension Center. ((Accessed December 1, 2014) http://oprec.okstate.edu/animal-science/research-newsletters/by-topic/Update%20Aug%202014.pdf)

Hoxey, R.P., Kettlewell, P. J., Meehan, A.M., Baker, C. J., and Yang, X. 1996. An investigation of the aerodynamic and ventilation characteristics of poultry transport vehicles. 1. Full-scale measurements. Journal of Agricultural Engineering Research 65:77-83.

Jacobs, L. 2016. Road to better welfare: welfare of broiler chickens during transportation. PhD dissertation, Ghent University.

Jones, R. B. 1992. The nature of handling immediately prior to test affects tonic immobility fear reactions in laying hens and broilers. Applied Animal Behavioural Science. 34:247-254.

Jones, S. D. M., and Tong, A.K. 1989. Factors influencing the commercial incidence of dark cutting beef. Canadian Journal Animal Science 69:649-654.

Jury, L. L. R. 2013. Effect of trailer stocking density on cattle behavior during truck transport. Master of Science Thesis. Mississippi State University.

Kannan, G., and Mench, J.A. 1997. Prior handling does not significantly reduce the stress response to preslaughter handling in broiler chickens. Applied Animal Behaviour Science 51:87-99.

Kenny, F. J., and Tarrant, P.V. 1987. The physiological and behavioral responses of crossbred Friesian steers to short-haul transport by road. Livestock Production Science 17:63-75.

Kettlewell, P. J., Hampson, C. J., Green, N. R., Teer, N. J., Veale, B. M., and Mitchell, M.A. 2001a. Heat and moisture generation of livestock during transportation. Pages 519-526 In Proceedings of the 6th International Livestock Environment Symposium, Louisville, KY.

Kettlewell, P. J., Hoxey, R. P., Hampson, C. J., Green, N. R., Veale, B. M., and Mitchell, M. A. 2001b. Design and operation of a prototype mechanical ventilation system for livestock transport vehicles. Journal of Agricultural Engineering Research 79: 429-439.

Kettlewell, P., Mitchell, M., and Harper, E. 2005. Livestock transport vehicles: A guide to best practice ventilation. Department for environmental food and rural affairs. Accessed July 28, 2016 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file /69375/pb11260-livestock-vehicle-ventilation-051104.pdf

Kettlewell, P.J, Hoxey, R.P., and Mitchell, M.A. 2000. Heat produced by broiler chickens in a commercial transport vehicle. Journal of Agricultural Engineering Research 75:316-326.

Knezacek, T.D., Olkowski, A.A., Kettlewell, P.J., Mitchel, M.A., and Classen, H.L. 2010. Temperature gradients in trailers and changes in broiler rectal and core body temperature during winter transportation in Saskatchewan. Canadian Journal of Animal Science 90:321-330.

Knowles, T. G., Warriss, P.D., Brown, S.N., and Edwards, J.E. 1999. Effects on cattle of transportation by road for up to 31 hours. The Veterinary Record 145:575-582.

Knowles, T.G., Warriss, P.D., Brown S.N., Edwards, J.E., and Mitchell, M.A. 1995. Response of broilers to deprivation of food and water for 24 hours. British Veterinary Journal 151:197-202.

Kolb, E., and Seehawer, J. 2001. Significance and application of ascorbic acid in poultry. Archiv fur Gerflugelkunde 65:106-113.

Kreikemeier, K. K., Unruh, J.A., and Eck, T.P. 1998. Factors affecting the occurrence of dark-cutting beef and selected carcass traits in finished beef cattle. Journal of Animal Science 76:388-395.

Lambooy, E. 2014. Transport of Pigs. Livestock Handling and Transport. Vol 4. 280-297. CABI Publishing, Wallingford, UK.

Lambooy, E., and Engel, B. 1991. Transport of slaughter pigs by truck over a long distance: some aspects of loading density and ventilation. Livestock Production Science 28:163-174.

Lambooy, E. Van der Hel, W., Hulsegge, B., and Brandsma, H.A. 1987. Effect of temperature on air velocity two days pre-slaughtering on heat production, weight loss, and meat quality in non-fed pigs. Energy Metabolism in Farm Animals: Effect of Housing, Stress, and Disease. 57-71.

Lambooy, E., and Hulsegge, B. 1988. Long-distance transport of pregnant heifers by truck. Appl. Animal Behavioral Science 20:249-258.

Lambooy, E., Garssen, G.J., Walstra, P., Mateman, G., and Merkus, G.S.M. 1985. Transport of pigs by car for two days: some aspects of watering and loading density. Livestock Production Science 13:289-299.

Lucas, E.M., Randall, J.M., and Meneses, J.F. 2000. Potential for evaporative cooling during heat stress periods in pig production in Portugal (Alentejo). Journal of Agricultural Engineering Research 76:361-371.

Magdesian, K. G., and Smith, B.P. 2002. Diarrhea. Large animal internal medicine. 3rd edition. St. Louis (MO): Mosby, 102-8.

Mallia, J. G., Vaillancourt, J.P., Martin, S.W., and McEwen, S. A. 2000. Risk factors for abattoir condemnation of turkey carcasses due to cyanosis in southern Ontario. Poultry Science 79:831-837.

Malmfors, E. 1982. Studies on some factors affecting pig meat quality. Proceedings of the 28th European Meeting of Meat Research Workers, Madrid, Spain, 21-23.

Marahrens, M., Kleinschmidt, N., Di Nardo, A., Velarde, A., Fuentes, C., Truar, A., Otero, J., Di Fede, E., and Dalla Villa, P. 2011. Risk assessment in animal welfare-especially referring to animal transport. Preventative Veterinary Medicine 102:157-163.

Mayes, H.F., and Jesse, G.W. 1980. Heartrate data of feeder pigs. ASAE Technical Paper No. 80-4023, American Society of Agricultural Engineers, St. Joseph, Michigan.

McGlone, J.J., Johnson, A.K., Sapkota, A., and Kephart, R.K. 2014. Transport of Market Pigs: Improvements in Welfare and Economics. Livestock handling and transport. Vol 4. 298-314. CABI Publishing, Wallingford, UK.

Merck Veterinary Manual. 2008. 9th Ed. Merck & Co., Inc. Whitehouse Station, NJ.

Merritt Equipment Co. 2017. Merritt Heritage. Oct. 4, 2017. http://merritt-trailers.com/new-trailers/commodity-trailers.html.

Mitchell, M. A., and Kettlewell, P.J. 2008. Engineering and design of vehicles for long distance road transport of livestock (ruminants, pigs, and poultry) Veterinary Italia 44:201-213.

Mitchell, M.A., Kettlewell, P.J., and Mazwell, M.H. 1992. Indicators of physiological stress in broiler chickens during road transportation. Animal Welfare 1:92-103.

Mota-Rojas, D., Becerril, M., Lemus, C., Sanchez, P., Gonzalez, M., Olmos, S.A., Ramirez, R., and Alonso-Spilsbury, M. 2006. Effects of mid-summer transport duration on pre- and post-slaughter performance and pork quality in Mexico. Meat Science 73:404-412.

Muirhead, V.V. 1983. An Investigation of the Internal and External Aerodynamics of Cattle Trucks. NASA Contract 170400, Kansas University Center for Research, Inc. https://ntrs.nasa.gov/search.jsp?R=19830018489

NFACC (National Farm Animal Care Council). 2017. Code of Practice for the care and handling of hatching eggs, breeders, chickens, and turkeys. National Farm Animal Care Council. Oct. 8, 2017. http://www.nfacc.ca/pdfs/codes/poultry_code_EN.pdf

Nielsen, B.L., Dybkjaer, L., and Herskin, M.S. 2011. Road transport of farm animals: effects of journey duration on animal welfare. Animal 5:415-427.

Nienaber, J. A., Hahn, G.L., and Ehrlemark, A. 1993. Heat and Moisture Production and Dissipation in Beef Cattle. Roman L. Huskra U.S. Meat Animal Research Center. Paper 141. Accessed Nov. 20, 2016. http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1140&context=hruskareports.

Nijdam, E., Delezie, E., Lambooy, E., Decuypere, E., and Stegman, J. 2004. Factors influencing bruises and mortality of broilers during catching, transport and lairage. Poultry Science 83:1610-1615.

Pereira, D.F. and Nääs, I.A. 2008. Estimating the thermoneutral zone for broiler breeders using behavioral analysis. Computers and Electronics in Agriculture 62:2-7.

Petherick, J.C., and Phillips, C.J.C. 2009. Space allowances for confined livestock and their determination from allometric principles. Applied Animal Behaviorial Science 117:1–12.

Pezzaioli. 2017. Pezzaioli Trailer. Oct. 10, 2017. www.pezzaioli.co.uk.

Phillips, R.A., Thomson, B.K., and Fraser, D. 1988. Preferences tests of ramp designs for young pigs. Canadian Journal of Animal Science 68:41-48.

Pilcher, C.M., Ellis, M., Rojo-Gómez, A., Curtis, S.E., Wolter, B.F., Peterson, C.M., Peterson, B.A., Ritter, M.J., and Brinkmann, J. 2011. Effects of floor space during transport and journey time on indicators of stress and transport losses of market-weight pigs. Journal of Animal Science 89:3809-3818.

Randall, J.M. 1992. Human subjective response to lorry vibration: implications for farm animal transport. Journal of Agricultural Engineering Research 52:295-307.

Randall, J.M. 1993. Humidity and water vapor transfer in finishing piggeries. Journal of Agricultural Engineering Research 28:451-46

Randall, J.M., Duggan, J.A., Alami, M.A. and White, R.P. 1997. Frequency weighting for the aversion of broiler chickens to horizontal and vertical vibration. Journal of Agricultural Engineering Research 68:387-397.

Ritter, M., Ellis, M., Benjamin, M., Berg, E., DuBois, P., Marchant-Forde, J., Green, A., Matzat, P., Mormede, P., Moyer, T., and Pfalzgraf, K. 2005. The fatigued pig syndrome. Journal Animal Science 83:258.

Ritter, M.J., Ellis, M., Anderson, D.B., Curtis, S.E., Keffaber, K.K., Killefer, J., Mckeith, F.K., Murphy, C.M., and Peterson, B.A. 2009. Effects of multiple concurrent stressors on rectal temperature, blood acid-based status, and longissimus muscle glycolytic potential in market-weight pigs in two commercially available types of trailer. Journal of Animal of Science 86:3137-3145.

Ritz, C. W., Webster, A. B., and Czarick III, M. 2005. Evaluation of hot weather thermal environment and incidence of mortality associated with broiler live haul. Journal of Applied Poultry Research 14: 594-602.

Santurtun, E., and Phillips, C. 2015. The impact of vehicle motion during transport on animal welfare. Research in Veterinary Science 100:303-308.

Scanga, J. A., Belk, K. E., Tatum, J. D., Grandin, T., and Smith, G.C. 1998. Factors contributing to the incidence of dark cutting beef. Journal of Animal Science 76:2040-2047.

Schuetze, S. J., Schwandt, E. F, Maghirang, R. G., and Thomson, D. U. 2017. Review: Transportation of commercial finished cattle and animal welfare considerations. Professional Animal Scientist 33:509-519.

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

Scott, E.B. 1994. Effects of short-term whole-body vibration on animals with particular reference to poultry. World's Poultry Science Journal 50:25-38.

Smulders, F.J.M., Romme, A.M.T.S., Woolthuis, C.H.J., de Kruijf, J.M., Eikelenboom, G., and Corstiaensen, G.P. 1983. Pres-stunning treatment during lairage and pork quality. In: Eikelenboom, G. (ed.) Stunning of Animals for Slaughter. Martinus Nijhoff, The Hague, The Netherlands. 90-95.

Sommavilla, R., Faucitano, L., Gonyou, H., Seddon, Y., Bergeron, R., Widowski, T., Crowe, T., Connor, L., Scheeren, M.B., Goumon, S. and Brown, J. 2017. Season, Transport Duration and Trailer Compartment Effects on Blood Stress Indicators in Pigs: Relationship to Environmental, Behavioral and Other Physiological Factors, and Pork Quality Traits. Animals 7:8.

Speer, N. C., Slack, G., and Troyer, E. 2001. Economic factors associated with livestock transportation. Journal of Animal Science 79:166-170.

Stanford, K., Bryan, M., Peters, J., González, L.A., Stephens, T.P., and Schwartzkopf-Genswein, K.S. 2011. Effects of long-or short-haul transportation of slaughter heifers and cattle liner microclimate on hide contamination with Escherichia coli O157. Journal of Food Protection 74:1605-1610.

Stermer, R. A., Camp, T.H., and Stevens, D.G. 1982. Feeder cattle stress during handling and transportation. Transactions of the ASAE 25:246–249.

Stevens, D. G., and T.H. Camp. 1979. Vibration in a livestock vehicle. American Society of Agricultural Engineers, St. Joseph, MI.

Sutherland, M. A., McDonald, A., and McGlone, J. 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. Veterinary Record 165:13-18.

Swanson, J. C., and Morrow-Tesch, J. 2001. Cattle transport: Historical, research, and future perspectives. Journal of Animal Science 79:102–109.

Tarrant, P.V. 1989. The effects of handling, transport, slaughter, and chilling on meat quality and yield in pigs- a review. Irish Journal of Food Science and Technology 13:79-107.

Tarrant, P.V., and Grandin, T. 2000. Cattle transport. Livestock handling and transport, Vol. 4, 151-173. CABI Publishing, Wallingford, UK.

Tarrant, P.V., Kenny, F.J., and Harrington, D. 1988. The effect of stocking density during 4 hour transport to slaughter on behavior, blood constituents and carcass bruising in Friesian steers. Meat Science 24:209-222.

Tarrant, P.V., Kenny, F.J., Harrington, D., and Murphy, M. 1992. Long distance transportation of steers to slaughter: effect of stocking density on physiology, behaviour and carcass quality. Livestock Production Science 30:223-238.

Terlouw, E.M.C., Arnould, C., Auperin, B., Berri, C., Le Bihan-Duval, E., Deiss, V., Lefevre, F., Lensink, B.J., and Mounier, L. 2008. Pre-slaughter conditions, animal stress and welfare: current status and possible future research. Animal 2:1501–1517.

Thomson, D. U., Loneragan, G. H., Henningson, J. N., Ensley, S., and Bawa, B. 2015. Description of a novel fatigue syndrome of finished feedlot cattle following transportation. Journal of American Veterinary Medicine Association 247:66-72.

Tucker, C. B., Coetzee, J. F., Stookey, J. M., Thomson, D. U., Grandin, T., and Schwartzkopf-Genswein, K. S. 2015. Beef cattle welfare in the USA: identification of priorities for future research. Animal Health Research Reviews 16:107-124.

Tuyttens, F., Vanhonacker, F., and Verbeke, W. 2014. Broiler production in Flanders, Belgium: current situation and producers' opinions about animal welfare. World's Poultry Science Journal 70:343-354.

USDA NASS. 2012. Quarterly Hogs and Pigs. United States Department of Agriculture, Food Safety and Inspection Service, Washington, D.C.

USDA NASS. 2014. Turkey Industry Overview. United States Department of Agriculture. Oct. 6, 2017. https://www.nass.usda.gov/Publications/Highlights/2013_Turkey_Industry/2013%20Turkeys%20Highlights.pdf.

USDA. 1994. Twenty-Eight Hour Law. National Agricultural Library. http://www.depts.ttu.edu/animalwelfare/Research/Transport/28hourslaw.php.

USDA. 2016. Economic Research Service. Statics & Information. Nov. 30, 2016. https://www.ers.usda.gov/topics/animal-products/cattle-beef/statistics-information.aspx.

Van Putten, C., and Elshof, W.J. 1978. Observation of the effects of transport on the well being and lean quality of slaughter pigs. Animal Regulation Studies 1:247-271.

Veerkamp, C.H. 1986. The influence of fasting and transport on yields of broilers. Poultry Science 57:619-627.

Von Borell, E. H. 2001. The biology of stress and its application to livestock housing and transportation assessment. Journal of Animal Science 79:260-267.

Vosmerova, P., Chloupek, J., Bedanova, I., Chloupek, P., Kruzikova, K., Blahova, J., and Vecerek, V. 2010. Changes in selected biochemical indices related to transport of broilers to slaughterhouse under different ambient temperatures. Poultry Science 89:2719-2725.

Warren, L.A., Mandell, I.B., and Bateman, K.G. 2010a. An audit of transport conditions and arrival status of slaughter cattle shipped by road at an Ontario processor. Canadian Journal of Animal Science 90:159–167.

Warren, L.A., Mandell, I.B., and Bateman, K.G. 2010b. Road transport conditions of slaughter cattle: Effects on the prevalence of dark, firm and dry beef. Canadian Journal of Animal Science 90:471-482.

Warriss, P. D., Brown, S. N., Knowles, T. G., Kestin, S. C., Edwards, J. E., Dolan, S. K., and Phillips, A. J. 1995. Effects on cattle of transport by road for up to 15 hours. The Veterinary Record 136:319-323.

Warriss, P. D., Knowles, T. G., Brown, S. N., Edwards, J. E., Kettlewell, P. J., Mitchell, M. A., and Baxter, C. A. 1999. Effects of lairage time on body temperature and glycogen reserves of broiler chickens held in transport modules. The Veterinary Record 14: 218-222.

Warriss, P.D., and Brown, S.N. 1983. The influence of pre-slaughter fasting on carcass and liver yield in pigs. Livestock Production Science 10:273-282.

Warriss, P.D., Kestin, S.C., Brown, S.N., and Bevis, E.A. 1988. Depletion of glycogen reserves in fasting broiler chickens. British Poultry Science 29:149-154.

Warriss, P.D., Pagazaurtundua, A., and Brown, S.N. 2005. Relationship between maximum daily temperature and mortality of broiler chickens during transport and lairage. British Poultry Science 46:647-651.

Weeks, C.A. 2014. Poultry Handling and Transport. Livestock handling and transport. Vol 4. 378-398. CABI Publishing, Wallingford, UK.

Weeks, C.A., and Kestin, S.C. 1997. Vehicle design and thermal comfort of poultry in transit. British Poultry Science 38:44-474.

Weeks, C.A., Brown, S.N., Richards, G.J., Wilkins, L.J. and Knowles, T.G. 2012. Levels of mortality in hens by the end of lay on farm and in transit to slaughter in Great Britain. Veterinary Record 170:647.

Werner, C., Reiners, K., and Wicke, M. 2007. Short as well as long transport duration can affect the welfare of slaughter pigs. Animals Welfare 16:385-389.

White, B. J., Blasi, D., Vogel, L.C., and Epp, M. 2009. Associations of beef calf wellness and body weight gain with internal location in a truck during transportation. Journal of Animal Science 87:4143–4150.

Whiting, T. L. 2000. Comparison of minimum space allowance standards for transportation of cattle by road from 8 authorities. The Canadian Veterinary Journal 41:855.

Whittier, J. C. 1993. Hot weather livestock stress. Extension publications (MU). https://mospace.umsystem.edu/xmlui/bitstream/handle/10355/3392/HotWeatherLivestockStress.pdf?sequence=1&isAllowed=y.

Wichman, A., Norring, M., Voutilla, L. Pastell, M., Valros, A., Algers, B., and Hanninen, L. 2012. Influence of crate height during slaughter transport on the welfare of male turkeys 53:414-420.

Williams, J.L., Richert, B.T., Marchant-Ford, J.N., and Eicher, S.D. 2012. Behavioral changes in neonatal swine after an 8-hour rest during prolonged transportation. Journal of Animal Science 90:3213-3219.

Wilson Trailer. 2017a. Wilson Trailer Company Information and History. Oct. 4, 2017. http://www.wilsontrailer.com/about.

Wilson Trailer. 2017b. Wilson Trailer Company. Livestock Trailers. Oct. 10, 2017. www.wilsontrailer.com/livestock-trailers.

Xiong, Y., Green, A., and Gates, R.S. 2015. Characteristics of trailer thermal environment during commercial swine transport managed under U. S. industry guidelines. Animals 5:226-244.