A WESTERN CANADIAN STUDY OF THE EFFECT OF WINTER TRANSPORT CONDITIONS INCLUDING ACCELERATION ON ANIMAL OUTCOMES IN CATTLE

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By

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LIST OF ABBREVIATIONS

Abbreviation	Definition
AMI	American Meat Institute
BA	Back anterior
BC	Body condition
BCRC	Beef Cattle Research Council
BCS	Body Condition Score
BIXS	Beef Infoxchange System
BFI	Beef Improvement Federation
BP	Back posterior
BRD	Bovine respiratory disease
BSE	Bovine spongiform encephalopathy
CACC	Canadian Animal Care Council
CARC	Canadian Agri-Food Research Council
CBBC	Canadian Beef Breeds Council
CBGA	Canadian Beef Grading Agency
CCA	Canadian Cattlemen's Association
CCIA	Canadian Cattle Identification Agency
CFIA	Canadian Food Inspection Agency
COP	Code of Practice
COPB	Code of Practice for the Care and Handling of Beef Cattle
COPT	Recommended Code of Practice for the Care and Handling of Farm Animals – Transportation
CLT	Canadian Livestock Transport Certification Program
CPK	Creatine phosphokinase
cm	centimeter
°C	Degrees celsius
DFD	Dark firm dry meat
DRSA	Difference from recommended space allowance (%)
EU	European Union
FFT	Fast fourier transformation
FWD	Feed and water deprivation
GLMM	Generalized linear mixed model
GPS	Global positioning system
HR	Humidity ratio (g water/kg dry air)
h	Hour (s)
Hz	Hertz
k	Allometric coefficient
Kg	Kilogram
km	Kilometer
lb	Pound (s)
LL	Left loin
m	Meter
mCOOL	Mandatory Country of Origin Labeling

min	Minute (s)
n	Number
NFAHW	National Farmed Animal Health and Welfare Council
NFACC	National Farm Animal Care Council
NBQA	National Beef Quality Audit
OIE	World Organization for Animal Health
OR	Odds ratio
PAACO	Professional Animal Auditor Certification Organization
PSE	Pale soft exudative
r	Correlation coefficient
r^2	Coefficient of determination
R	Round
RFID	Radio frequency identification
RL	Right loin
rms	Root mean square
s	Second (s)
SA	Space allowance (m^2/animal)
SAS	Statistical Analysis Software
SD	Standard deviation
T	Tail
TAHC	Terrestrial Animal Health Code
THI	Temperature Humidity Index
US	United States of America
wt	Weight
Y1	Yield grade 1
Y2	Yield grade 2
Y3	Yield grade 3
ΔTemp (°C)	Difference in temperature between the trailer interior and ambient
ΔHR (g water /kg dry air)	Difference in humidity ratio between the trailer interior and ambient
ΔTHI	Difference in temperature humidity index between the trailer interior and ambient
>	Greater than
<	Less than
%	Percent

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ABSTRACT

Kehler, Carollyne Elizabeth Joan. M.Sc., The University of Manitoba, 2015. The effect of winter transport on animal outcomes for fed cattle and market cows in western Canada. Advisors: K.H. Ominski and K. Schwartzkopf-Genswein.

The intent of this study was to monitor the effect of Canadian winter commercial transport conditions on animal outcomes. A methodology was developed to measure acceleration on trailers transporting cull cows and a preliminary comparison of acceleration and carcass bruising revealed that further study of the relationship was warranted. The accelerometer methodology was used as one tool to examine factors influencing internal trailer microclimate and trailer acceleration on shrink, and severe bruising in finished cattle. This research has improved our understanding of Canadian winter transport conditions affecting finished cattle and demonstrated that there is a relationship between vertical rms of acceleration (P=0.0025), beta agonist use (P=0.0323), total wait time (P=0.0052) and the two way interaction of carcass position and yield score (P=0.0025) with cattle bruising. It also demonstrated that there is a relationship between journey duration (P<0.001), allometric coefficient (P<0.001), temperature humidity index (P<0.001) and prod use during loading (P=0.0012) with cattle shrink.

FOREWARD

This thesis is written in manuscript style for publication in the Canadian Journal of Animal Science, with each manuscript having its own abstract, introduction, materials and methods, results, discussion and conclusions. There is also a general introduction, literature review, discussion and conclusions, followed by the literature cited. None of the manuscripts have been submitted for publication at the time of thesis completion.

1. GENERAL INTRODUCTION

The transport of livestock, specifically cattle, has evolved over the course of the last century. It was once an industry in which the majority of livestock were transported relatively short distances to local feedlots, auction houses and slaughter facilities within their province of origin. It has become an industry in which the majority of cattle are transported thousands of kilometers to slaughter facilities that have the capacity to process in excess of 5000 animals in a day. Large federally inspected cattle processing facilities in Canada number in the single digits, consequently, transport durations can range from < 1 h to multiple days for finished cattle to reach these processing facilities (Warren et al. 2010a; González et al. 2012b).

As the livestock transport industry has evolved, so have consumers. They have become further dissociated from livestock production and may be more vulnerable to influence by radical groups, which often don't understand the significant research investment that is continually being directed towards improving livestock transport. In October of 2014, Mercy For Animals, an animal rights group, brought a petition signed by 80,000 people, to the federal government of Canada to demand improvements to livestock transport. Likely they were unaware of the fact that there has been a substantial research effort, in recent years, to find applicable ways of improving cattle transport (Goldhawk et al. 2014 a,b,c,d; González et al. 2012 a,b,c,d). Consumers should view the cattle transport industry positively because there are valid improvements to transport currently being initiated by the industry. These initiatives will help counteract unsubstantiated negative attention from groups of this nature, especially if the results are successfully communicated throughout the industry and to the public.

Livestock transport is complex in nature. A single, untested, regulation change may not have the desired level of impact on animal welfare because of the many other variables involved. In fact, these changes risk reducing the industry's productivity, while maintaining only a minimal impact on animal health and welfare (Mitchel et al. 2008). Rather, the whole system needs to be considered including; the behaviour of the livestock; the skill level of the handlers or drivers; and the design and condition of the handling and transporting equipment, before regulations are changed. Scientifically sound, practical regulation changes can result in increases in animal health, productivity, and welfare that counteract any production losses in other aspects of transport (Schwartzkopf-Genswein et al. 2012; Grandin 2014).

Finished cattle are reported to be the lowest risk for welfare and carcass quality concerns (González et al. 2012c) compared to other classes of cattle (calves, feeder cattle and cull cows) and therefore have received much less attention regarding opportunities to change management practices. However, they are the main economic drivers of the industry and therefore deserve adequate attention. The information from this thesis will supplement transport work already done on the other cattle classes and will serve to broaden and complete the understanding of cattle transport in Canada (González et al. 2012c). The ultimate goal of this thesis is to be able to identify critical control points in transportation management and provide information for science-based recommendations to be made to government and industry. This information will aid in creating transport industry changes and regulation modifications that are both practical and have the greatest possible positive impact on cattle health and welfare.

There were two hypothesis: 1) that increased acceleration during transport would detrimentally affect cattle carcass characteristics; and 2) that finished cattle would have good overall welfare during typical winter transport conditions although specific characteristics of the transport might affect animal welfare and carcass quality; such as microclimate, transport duration, handling, loading and unloading. There were a number of objectives of this thesis; (1) to develop and validate a method of measuring trailer motion (acceleration) in cattle transport trailers, (2) to apply this method to trailers transporting cull cows and finished cattle to determine the impact of motion on cattle welfare and carcass quality (3) to determine pre, post and in-transit descriptive statistics of commercial finished cattle loads in Canadian winter conditions (4) to determine transport variables that affect the acceleration and internal trailer microclimate (5) and to determine the relationship between indicators of animal welfare (bruising and shrink) and transport variables.

2. LITERATURE REVIEW

Although representing brief portion of an animal's life, transport is critical to cattle health and welfare as it serves to connect different sectors of the cattle industry (Eldridge et al. 1986). Further, transport is the most publicly visible portion of beef production, which makes it a candidate for criticism from consumers. Consumers are increasingly concerned about how their food is produced, where it is coming from and who produced it; therefore transparency is of paramount importance for maintaining consumer acceptance and confidence (Olynk 2012). Consumers have the ability to influence regulation, legislation and markets using political and purchasing pressure (Olynk 2012). Pro-active research and industry support for the development of transport standards are important to ensure that regulators use scientifically-validated information rather than unsubstantiated misinformation from lobby groups. This is especially important in light of the Canadian Food Inspection Agency's (CFIA) ongoing initiative to modernize the Federal Health of Animals Act and the previous lack of sufficient research on transport in Canada, which is just recently being remedied (CFIA 2005; Doonan et al. 2008; Schwartzkopf-Genswein et al. 2012).

2.1 TRANSPORT AS AN INTEGRAL PART OF BEEF PRODUCTION

In Canada there are some 12 million head of beef cattle (Canfax 2012). These animals are transported from their place of origin to a variety of destinations, usually at least once in their lifetime but often many more times. The cattle production cycle in North America typically involves transport of cattle from one area to another of the same ranch, to an auction yard for sale, to a back-grounding operation for growing, to a feedlot for finishing and ultimately to a processing plant for slaughter (Schwartzkopf-Genswein et al. 2012). In Canada, the majority of live cattle exports are transported into the United States for finishing or slaughter but there is also a market for Canadian genetics (semen and breeding animals) in over 50 other countries (CBBC 2012). Cattle have been transported by sea, rail, road and air but road transfer is now the most significant in terms of economics and magnitude (Tarrant 1990; Swanson et al 2001) and will be the focus of further discussion.

2.1.1 An international perspective

There are more than 1 billion head of cattle globally that are dispersed throughout beef producing nations and therefore transport is a fundamental production practice. In the European Union (EU) approximately 365 million head of livestock are transported across borders every year (Fike et al. 2006), in Australia, approximately 1 million cattle are exported each year (Kinery et al. 2003), and in the US approximately 934,000 loads of cattle are transported each year (Minka et al. 2009). This movement of cattle within and between countries is why humane transport is essential to successful beef production and trade in a global market.

Canada, as a nation, is the 5th largest exporter of beef worldwide making the countries beef production reliant on export markets (Canfax 2015). In order for Canada to continue transporting beef and cattle into the global market Canada must meet the rigorous importing standards of other countries (CCA, 2012). Maintaining an efficiently and humanely produced high-quality product will ensure that this is possible. One component of producing a reliable end-product is maintaining quality at critical control points, such as during transport. Currently, Canadian transport legislation is less stringent than some other countries (specifically the EU's) standards especially in the area of transport duration, as well as feed and water deprivation (Warren et al. 2010a). The recent Canadian- European Trade Agreement (CETA) (CCA 2012) is a huge opportunity to expand Canada's export market; the EU could rival the US as a destination for Canadian beef exports. It would be in Canada's best interest to have standards of cattle transport that meet or exceed the EU's expectations. Currently, Canada's major export destinations are the US and China/Hong Kong with 93% of the exports in both dollars and tonnes (Canfax 2015). However, securing other markets could ensure future market stability especially in light of the past and current trade barriers with the US due to bovine spongiform encephalopathy (BSE) and mandatory country of origin labeling (mCOOL) (Canfax 2012; CCA 2012). Meeting or exceeding foreign trading partners' standards of animal welfare, including during transport, will be important to Canada's future as a major exporter of cattle and beef products.

2.1.2 A Canadian perspective

Transport is an integral part of the production cycle in Canada because of the expansive distance that animals must travel to slaughter. There are only a select few federally inspected slaughter facilities located in some, but not all, provinces in Canada. As beef cattle are raised across the entire country, many of them must be transported for long distances to reach these facilities. Improving upon transport procedures is essential to consumer acceptance of cattle production and assured animal welfare during transport. In 2009, the National Farmed Animal Health and Welfare Council (NFAHW 2009) recognized the need for the cattle industry to anticipate the growing public concern for animal health and welfare. According to their report, "demands for heightened standards in food safety and improved animal welfare are becoming increasingly intense." Therefore, ensuring animal welfare during transport has become a priority in the Canadian beef cattle industry, which is reflected in the commitment to transport research and development of programs such as the Canadian Livestock Transport Certification Program (CLT), which was introduced in 2013. In 2010, the Canadian Animal Care Council (CACC) supported the initiative to develop CLT into a nationally recognized program (CLT 2015). The CLT program is committed to increasing the knowledge and expertise of the drivers, shippers and receivers of transported animals. It has species-specific training programs for transporters, which focus on animal behaviour, complex logistics of livestock trucking, impact of transport on quality, legislation, enforcement, and best management practices.

Continued transport research is integral to improving transport in Canada so that standards can be applicable to the transport conditions and production systems used here. The Canadian Agri-Food Research Council (CARC) developed the Transport Codes of Practice (COPT) for the care and handling of farm animals in 2001. These codes were based on research that, although informative, was conducted prior to 2001 and was not conducted in Canadian conditions. Only one of the cattle studies cited in the COPT took place in Canada, the rest of the research was in Europe, Australia and the US (Schaefer et al. 1990). Since then, research regarding cattle transport has been encouraged by the CFIA (CCA 2011). In 2011, the Beef Cattle Research Council (BCRC) committed 15% of their funding to animal health and welfare research, focused on the effect of ventilation management strategies and stocking density during transport on trailer microclimate and calf welfare (CCA 2011). Alberta Beef Producers and Ontario Cattlemen's Association were also vital in the advancement and funding of research to identify the current Canadian practices and transport conditions and how these practices affect animal outcomes (Thrower 2009; González et al. 2012b). Research regarding transport continues to be a priority for the Canadian government and industry groups both provincially and nationally.

2.2 CURRENT CANADIAN REGULATIONS

2.2.1 Provincial Animal Welfare Acts

Most provinces have Animal Welfare Acts that are used to prosecute offenders in cases of poor animal welfare if the offense is unrelated to transport. Alberta, Saskatchewan and Manitoba have quite thorough Animal Welfare Acts that are enforced by the Society for the Protection of Animals in Alberta and Saskatchewan and by a provincially appointed department veterinarian in Manitoba (Winter 2011). The provincial animal care acts will not be discussed in this review because they are not related to livestock transport or slaughter; however, they are important for regulating animal welfare and humane care in all other areas of livestock production.

In each province, the specific Code of Practice (COP) for each species is used as a reference point to provide further detail regarding best management strategies except in the case of transport because it has its own specific code of practice.

Federal Health of Animals Act and Meat Inspection Act

There are several federal regulations in place to protect the welfare of cattle while they are being transported and when they arrive at their destination. The federal regulations are described in the Health of Animals Act Part XII and the Meat Inspection Act Part III, which are enforced by the CFIA (Winter 2011; Department of Justice 2015a,b). A person convicted of breaking the regulations stated within these acts may receive a warning, be forced to take an educational course or pay fines of up to $10,000 for a first time offender (Winter 2011). In order to enforce these regulations, a CFIA inspector can examine an animal transport vehicle at any time (Department of Justice, 2015 a;b). Inspections during transport can occur between the point of origin and the final destination, which includes assembly yards and auction marts.

Regulations under the Meat Inspection Act require that every shipment of beef animals and every individual animal that arrives at a federally inspected slaughter facility must be examined by an appointed veterinarian or an inspector under the supervision of a veterinarian (Department of Justice 2015b). The federally inspected slaughter facilities in Canada slaughter 95% of the total cattle in Canada. The other 5% are slaughtered at provincial processing plants (Department of Justice 2015b). The regulations in the Meat Inspection Act cover lairage conditions (the time between unloading and slaughter of cattle at a processing facility), animal handling techniques, examination of animals before slaughter, the action required to deal with sick or injured animals (for example segregation or treatment), and proper disposal of condemned animals. This Act also regulates the slaughter method, post-mortem examination and inspection, packaging and labeling.

The requirements of the Federal Health of Animals Act will be discussed in the next section, along with the national transport codes of practice since they cover many of the same topics.

2.2.2 National Transport Codes of Practice

Although the Health of Animals Act serves as the basis for setting transport standards, recommendations developed by the Canadian Agri-Food Research Council (CARC 2001) delve deeper into the details of transporting different species of livestock. The ‘Recommended Code of Practice for the Care and Handling of Farm Animals – Transportation (COPT; CARC 2001)’ is a

75-page summary of recommendations that are used to improve the safety and efficiency of transporting livestock. It offers individuals involved in the industry a way to compare their methods of transport to others (NFACC 2012). Although, the COPT provides guidelines, not regulation, it should be noted that the code has been accepted as the standard of practice and has been recognized as such by the courts (CARC 2001). The first version of this document was developed in 2001 and is the current version in use today. A major portion of the transport code applies to all livestock species but specialized recommendations are made for each species. There are also sections for air, sea and road transport but this review will focus on the recommendations related to road transport of cattle.

Who is responsible for cattle during transit?

The COPT states that the humane transport of animals is the responsibility of buyers, sellers, assembly point managers and truckers. All should ensure that the journey of the animals is as safe and short as possible. The driver of the truck is responsible for the care of the animals during transport on the truck. In Canada, drivers aren't officially required to take a course on livestock transport, however, some packing plants require drivers delivering cattle to have CLT training. As described above, the CLT program focuses on proper animal handling and transporting techniques and informs drivers of current regulations (CLT 2015).

Transporting unfit animals

The main emphasis of both the COPT and the Health of Animals Act is the prohibition of transporting unfit animals. An unfit or non-ambulatory animal is one that, "by reason of infirmity, illness, injury, fatigue or any other cause cannot be transported without undue suffering during the expected journey (Department of Justice 2015a)." The only time a non-ambulatory animal can be transported is with advice from a veterinarian for treatment. If an animal becomes non-ambulatory during the journey the driver must stop at the nearest possible place that the animal could receive care.

The COPT emphasizes that animal welfare should be considered before economic considerations, including transport of an unfit animal to an auction mart or abattoir. Unfit or non-ambulatory animals should instead be euthanized on farm or rendered unconscious, slaughtered and brought to an abattoir (Figure 2.1). If on-farm slaughter is prohibited then the animal must be euthanized. If an animal becomes non-ambulatory during transit it must not be unloaded, instead it should be killed or stunned on the vehicle and then unloaded and immediately killed. The COPT also recognizes that special care should be taken when transporting cull cattle because they are at higher risk for poor welfare than other cattle types (CARC 2001; González et al. 2012b). Figure 2.1 displays a guide to making transport decisions regarding animals in poor condition.

A Guide to Handling Livestock at Risk

NON-COMPROMISED = an animal that can be transported without special provisions

LIVESTOCK ON FARM

ANIMAL AT RISK = an animal with reduced capacity to withstand the stress of transportation, due to injury, fatigue, infirmity, poor health, distress, very young or old age, impending birth, or any other cause

CAN TRANSPORT WITH SPECIAL PROVISIONS

Abattoir	**** Closest abattoir**
Lameness – Class 2/3	Severe Eye Damage
Abscess – if animal can walk well	Lame – Class 4 eg
	Frozen / Frostbite
	Amputee
	Prolapsed vagina / rectum
	Recent injury
	Bloat – if not weak / down
	Pneumonia – No fever & no drugs
	* Blind
	Nervous Disease eg Listeria, ** **Notify veterinarian**

DO NOT TRANSPORT

EUTHANIZE (condemnable conditions)
Extremely thin
Infected or abscessed joints – 3 or more
Nervous disease & non-ambulatory
Unresponsive Pneumonia with fever
Dying / Shock / Severe Distress
Unresponsive Water Belly – SICK
MOBILE SLAUGHTER as per Provincial Regulations
Non Ambulatory i.e. Downer due to accident or injury
Lameness Class 5
DELAY TRANSPORTATION
Parturition (about to give birth)

LAMENESS CLASSES

Class 1 – Visibly lame but can keep up with group; no evidence of pain
Class 2 – Unable to keep up; some difficulty climbing ramps. **Load in rear compartment.**
Class 3 – Require assistance to rise be can walk freely.
Segregate. **Load in rear compartment**.
Class 4 – Require assistance to rise; reluctant to walk, halted movement; no steep ramps.
Class 5 – Unable to rise or remain standing.
Should not be moved; except with veterinary certification, using suitable specialized equipment, and in accordance with provincial regulations.
Euthanasia or Mobile Slaughter.

NOTES AND REFERENCES

- **Federal Health of Animal Regulations**
- **Recommended Code of Practice for the Care and Handling of Farm Animals**
- **Animals segregated in trucks require extra protection from cold and wind chill; ample bedding is required.**
- *** Blind animals should be put in a small compartment with one other quiet animal, or individually segregated.**
- **Producers must adhere to drug withdrawal times prior to slaughter.**

Adapted from Margaret Fisher, DVM

Figure 2.1 A guide to handling at-risk livestock. Source: CARC (2001)

Transport facilities and equipment

The Health of Animals Act has very few detailed requirements regarding the facilities and equipment used for the transport of cattle, likely because of the variety of transport methods used throughout the country. That being said, it does require that facilities receiving cattle provide protection from extreme weather and access to feed and water. The transporter must not cause undue suffering to the animals as a consequence of inadequate construction, protruding objects (fittings, bolt-heads, etc.), exposure to weather, inadequate ventilation or inadequate drainage. It is also required that sand or appropriate foothold and bedding (e.g. straw or wood shavings) be used to ensure secure footing and absorption of urine. Most commonly used cattle semi-trailers have raised treads on the trailer floor for secure footing but there is considerable variability regarding how many drivers actually comply with the sand or bedding requirements (Thrower 2009; González et al. 2012b). The Act includes regulations that state that transport vehicles must be tall enough to ensure the cattle can stand in their natural position without coming into contact with the roof. Facilities such as ramps and chutes must be maintained in good working order, with a slope of less than 45 degrees (an ideal slope for cattle is 25 °). Ramps should have sides with no gaps between the ramp and truck.

Additional requirements raised in the COPT (CARC 2001) include partitions which are strong and secure with quick release mechanisms; doors and gates should be large enough that animals can pass through them without injury; and no part of the animal should be able to protrude from the transport vehicle (CARC 2001). Further, to ensure adequate ventilation, aerodynamic airfoils on tractors must not restrict airflow into the vehicle, engine exhaust should not enter the trailer and vents should be adjustable from the outside of the vehicle. If steps are used instead of sloped ramps then the appropriate single step heights are listed in tables within the CARC (2001).

Animal handling

Animal handling is addressed in the Health of Animals Act, stating that, “No person shall load or unload, or cause to be loaded or unloaded, an animal in a way likely to cause injury or undue suffering to it,” and, “no person shall beat an animal being loaded or unloaded in a way likely to cause injury or undue suffering to it (Department of Justice 2015a).” The COPT (CARC 2001) also acknowledges animal handling as an important aspect of transport in that transporters should have knowledge of animal behaviour and be able to use animals’ flight zones, parameters of vision, social behaviour and response to stimuli to efficiently and humanly move livestock. Handlers should also be able to recognize if animals are showing signs of stress. The use of electric prods is strongly discouraged as there are other effective methods of moving cattle. A training period with an experienced animal handler is also recommended.

Space requirements

Space allowance in the Health of Animals Regulations are vague, stating only that animals shouldn’t be loaded or transported if the vehicle is so crowded that it causes undue suffering or pain (Department of Justice 2015a). When transporting cattle, groups of bulls must be separated from other animals and animals of substantially different weight or age must also be separated. Only cows with suckling offspring can be transported together but must be separated from the other livestock. Conversely, the COPT (CARC 2001) provides detailed information regarding loading density, including maximum trailer carrying capacity and minimum recommended area per animal by weight (Figure 2.2).

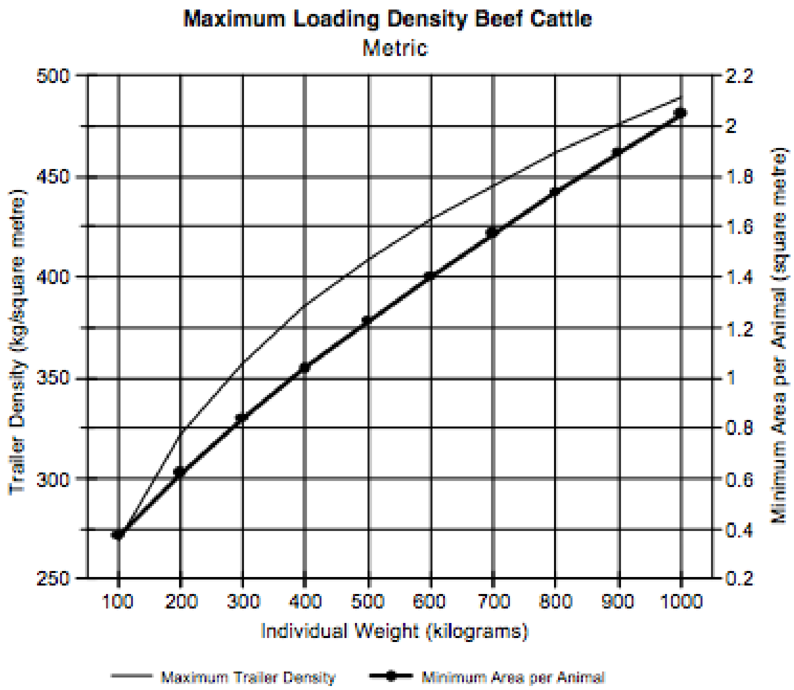

Figure 2.2 Minimum space allowance for cattle in transit based on average individual body weight (Metric). The top line describes maximum trailer carrying capacity (left hand axis); minimum space per animal is the bottom line and right hand axis. Source: CARC (2001)

* In cool weather, slaughter ready beef cattle in a high level of finish can be transported safely at 10% over this standard. Dairy cattle should not be loaded at more than 85% of this standard depending on the condition of the cattle. Thin animals require more space than a finished animal of the same weight.

Transport duration

In Canada, cattle must not be transported for longer than 48 h (without feed or water), in accordance with the Health of Animals Regulations, unless the destination can be reached within 52 h. If the final destination cannot be reached within this time frame then a rest stop is required where the animals are unloaded into a specified area for at least 5 h. This area should have space for all the animals to lie down, facilities for feed and water, safe footing, bedding and protection from the weather. The COPT (CARC 2001) recommends consideration be made for factors that might cause any delay in reaching the final destination including extreme weather, emergencies, en-route off-loading sites and hours of operation at final destination. The COPT (CARC 2001) states that feed and water must be provided within 5 h prior to a 24 h or longer trip, within 5 h prior to a 12 h trip and within 24 h prior to a 4 h trip.

Transport records

The Health of Animals Regulations require that transporters shipping inter-provincially and internationally maintain records including information on the shipper, consignee, driver, number and weight of animals, vehicle (registration and floor area), animal care provided (feeding, watering and resting), and the date of vehicles last cleaning and disinfecting. The date, time, and place of when the driver received custody and the subsequent unloading is also required. These records must be kept for two years and be available to CFIA inspectors whenever requested.

Canadian regulation compared to international regulation

There are significant differences between Canada and other countries with respect to transport regulations. For example, the EU only allows 8 h of transport without feed, water and rest while Canada's regulations allow up to 52 h (Warren et al. 2010a). The United States effectively has no regulation regarding the transport duration of livestock (except horses) (Fike et al. 2006). The World Organization for Animal Health (OIE) has developed international transport standards included in the Terrestrial Animal Health Code (TAHC) (OIE 2015). Although the TAHC has a very comprehensive transportation section it is lacking in detail. To ensure that all sectors of the industry involved in the transport of cattle comply with regulations they need to be clear, detailed and practical; avoiding subjective terms such as “should”, “adequate” or “proper” (Grandin 2007). Because of the lack of detail in the OIE regulations, they should be considered minimum guidelines and individual countries need more stringent regulations. Canada’s current regulations are quite thorough in comparison but may need revision if they are to compare to the regulations in countries that are current or prospective trading partners. However, caution should be taken that these revisions do not unnecessarily restrict industry competitiveness only for the sake of meeting standards that may not be appropriate for Canada’s specific transport conditions.

2.3 FACTORS AFFECTING THE WELFARE OF TRANSPORTED CATTLE

There are many aspects of transport that can have a varying degree of influence on cattle welfare including: noise, movement of the trailer, changes in social groups, environmental change, stocking density, deprivation of feed and water, handling as well as loading and unloading. Combined, they can create a time of major physiological and psychological stress on livestock (María et al. 2004). Stress related to transport can result in meat quality issues (such as dark cutting and bruising), compromised immune systems, injury, decreased production post transport and even death in the most severe cases (Schwartzkopf-Genswein et al. 2012). Thus transport affects not only animal welfare but also the financial returns to the industry as the animals are moved through the production system. That being stated, the stress of transport can be drastically reduced by manipulating aspects of the journey to better suit the animals’ needs. By doing so, transport can be a neutral or positive experience for the animals rather than an aversive one. Determining the needs of animals is not simple and researchers throughout the world have studied stress associated with transport in order to develop a better understanding of these needs.

Transport stress not only depends on the conditions associated with the journey itself but also on the animal type and previous experience (Le Neindre et al. 1995). The results of transport studies can therefore be highly variable and challenging to interpret, as they are often diverse in the conditions studied and the methods used to analyze them. Numerous studies have been conducted to assess individual stressors associated with transport including social regrouping (Boissy et al. 1997); feed and water deprivation (Hogan et al. 2007); vehicular vibrations (Gebresenbet et al. 2011); and ventilation (Giguere 2006). Other studies have utilized a more general approach by studying multiple aspects of transport simultaneously (Eldridge 1986; Palme et al. 2000). Studies using commercial transporters have also been conducted that analyze typical transport conditions with minimal interference of normal commercial transport practices (Thrower 2009; Warren et al. 2010a:b; María et al. 2004; González et al. 2012a:c:d; Polkinghorne et al. 2013). Other differences between studies include the type of transport trailer used and the environmental conditions of transport. In North America, for example, multiple decked semi-trailers are commonly used. However, in other countries different forms of transport such as ‘road trains’ in Australia, and single-decked stock trailers such as gooseneck tandem axle or bumper-pull trailers are used more commonly in Europe. Further, climate and season within and between countries can vary dramatically. The temperature in North America, for example, can vary between -42°C and 45°C (Schwartzkopf-Genswein et al. 2012). Each type of study and method of analysis are valid under the defined conditions and provide important information about the effect of transport on the welfare of livestock.

When studying transport stress it is necessary to choose outcomes with which to evaluate the level of stress experienced. Physiological measures, carcass quality, shrink, BCS and general animal condition are commonly used outcomes. Comprehensive studies of cattle transport conditions have been written by González et al. (2012c), Malena et al. (2006), Warren et al. (2010a) and Thrower (2009). Each of these studies used death as a transport outcome in order to determine poor transport conditions. Although the number of deaths during transport is informative other outcomes may be better suited to evaluating the level of stress, because animals can experience unacceptable levels of stress long before they reach the point of dying. Occurrences of cattle perishing during transport are evidence of the extreme endpoints of poor transport conditions. That is why it is important to consider other outcomes including, carcass quality or physiological measures, when evaluating the level of transport stress experienced by cattle.

2.3.1 Animal type and temperament

Differences in cattle welfare during transport can be due to animal type, including age, size and breed (Grandin 2007). González et al. (2012c) observed that the percentage of calves and cull cattle deaths (0.0653% and 0.0587% respectively) as well as the percentage of calves and cull cattle becoming non-ambulatory (0.1026% and 0.2934% respectively) during a long distance journey were higher than the percentage of feeder or finished cattle deaths (0.0151% and 0.0066% respectively) and those becoming non-ambulatory (0.0091% and 0.0203% respectively). During the study they also found that feeders were twice as likely to die during transport than finished cattle (González et al. 2012c). The higher risk associated with transporting calves has been attributed to the incomplete development of their immune system and exposure to stressful events, such as processing and weaning, prior to transport (Schwartzkopf-Genswein et al. 2012). It has been suggested that finished cattle have the lowest risk of dying or becoming compromised because of their generally high body condition score and vigorous immune system compared to cull cows, feeder cattle and calves (Schwartzkopf-Genswein et al. 2012).

Gender can also influence the outcome of a journey. González et al. (2012c) reported that male cattle were approximately two times more likely than female cattle to become compromised (lame, non-ambulatory or dead) during a journey ($P = 0.04$). However, heifers and steers, when transported together, were reported to have a higher incidence of dark cutting than loads of just heifers or steers (Warren et al. 2010a).

Temperament may also affect response to transport stressors. Warren et al. (2010a) reported that cattle with an unloading speed score of 3 (ran off the truck) had a much greater prevalence of dark cutters (1.49-1.46 times) than cattle with an unloading speed score of 1 or 2 (walked off the truck or trotted of the truck respectively). The speed scores above were considered a result of the animals' temperament and therefore a connection was made between temperament, affected by the transport experience, and animal outcomes such as dark cutting.

2.3.2 The formation of new social groups

Cattle are herd animals with very specific social groups (Boissy et al. 1997). Separation from herd-mates and/or isolation can therefore cause animals to become agitated and stressed. Responses such as struggling, vocalization, increased heart rate and raised plasma cortisol have all been reported when animals are separated from their herd-mates (Boissy et al. 1997).

Isolation has the greatest effect on the behavioural and physiological stress responses of cattle but introduction to new herd mates can further increase stress (Boissy et al. 1997). For example, Puolanne et al. (1981) found that bulls mixed in lairage rather than being penned individually had a higher incidence of dark cutters. Warren et al. (2010a) also found that mixing unfamiliar cattle during transport increased the occurrence of dark cutters. They suggested that mixing unfamiliar animals be avoided when possible even if there is an economic or logistic incentive to mix animals. Animals from multiple pens and from different producers are often sorted by breed, weight or sex in order to make uniform groups. This sorting technique can increase their sale price and enable processors to compare carcass characteristics between similar types of cattle with other types to determine their carcass merits (Warren et al. 2010a). However, the advantage gained by combining animals from different herds may be lost because of the added stress on the cattle and possible decreases in production. If at all possible it is best to keep familiar animals together during transport.

2.3.3 Animal management prior to transport; animal condition and origin

An animal's condition prior to transport will determine its ability to cope with the stress associated with transport (Fisher et al. 2009). Hogan et al (2007) suggested that animals with little feed in their rumen or limited rumen capacity, including young animals, or animals selected for rapid growth and high feed efficiency, have a harder time coping with the feed and water deprivation that is associated with transport, because of the small rumen holding-capacity or rapid movement of rumen contents through the system. In addition, González et al. (2012c) reported that older or cull cattle were more likely than feeder or finished cattle to experience poor welfare (becoming lame, non-ambulatory or dying) during transport because they were generally in the poorest condition prior to loading; putting them at a disadvantage before they even begin their journey.

Cattle that are loaded directly from a farm or feed-yard rather than from an auction mart are less likely to become compromised during a journey according to reports by Warren et al. (2010a) and González et al. (2012c). This may be because there are more stress-creating steps involved in a journey when cattle are transported from a farm to the auction mart, sorted, sometimes mixed, run through the sales ring and then transported at least one more time, rather than simply being transported once. Any events that serve to extend and exacerbate the stress of the journey including unloading and sale from an auction mart rather than direct sale from a farm may result in an increased number of compromised animals (González et al 2012c).

2.3.4 Feed and water deprivation (FWD)

It's common practice to deprive cattle of feed and water for a few h before and during transport. Feed and water deprivation (FWD) reduces an animal's digesta load and therefore reduces the rate of animals soiling each other, the trailer and the road. It has been suggested that supplying cattle with a low-quality or high-roughage forage prior to transport will increase the animals digesta load and promote a drier feces, which consequently reduces the dirtiness of the trailer and cattle (Hogan et al. 2007). The practice of FWD is also used in situations when cattle are sold by weight in order to regulate reductions in weight during a journey. The effects of FWD include both the weight loss (shrink) of an animal as well as their stress level in terms of physiology. During the first 24 h of transport cattle lose weight as urine and feces with most of this weight loss being in the first 12 h (Hogan et al. 2007). After approximately 12 h carcass weight loss can begin.

There are many ways in which FWD can be detrimental to transported animals, especially after long journeys. The effects of FWD can make it difficult for animals to regulate homeostasis because of changing rumen and blood pH, osmotic pressure and acid-base unbalance (Hogan et al. 2007). Further, lambs, which were transported with FWD, had higher plasma cortisol concentrations at the time of transport and for 2 days following transport than lambs that were transported without FWD and lambs that were not transported or subjected to FWD (control), suggesting that FWD amplifies the stress already associated with transport. As a result, control lambs had the highest weight gains and plasma glucose levels over the 32-day experiment (Horton et al. 1996). In addition, Tarrant et al. (1992) reported signs of dehydration, such as increases in the red blood count, hemoglobin, total protein and packed cell volume after 24h of transport. The effect of FWD can also be detrimental because it promotes the proliferation of pathogens such as Salmonella spp. and E. coli in the rumen and their subsequent shedding into the environment (Hogan et al. 2007). Salmonella and E.coli accumulation is a food safety risk factor and it is therefore essential to avoid their proliferation and shedding during transport.

Following FWD during transport a number of events must take place before a full recovery can occur. Most importantly a high-quality and suitable quantity of feed and water must be offered to the animals so that they can rebuild microbial populations in the rumen and large intestine, rehydrate tissues, restore electrolytes and restore enzymes in the liver and muscle (Hogan et al. 2007). This can take some time as the animals must also recover from the stress and fatigue of transport, adjust to their new surroundings, companions, and changes in their feed and water supply (Hogan et al. 2007).

2.3.5 Handling

Calm handling is key for keeping any livestock species relaxed and stress-free during human contact. The way in which animals react to handling depends on the type of animal and extent and nature of previous contact with humans. Extensively raised animals that have had little to no contact with humans can have very severe fear responses to handling (Fisher et al. 2009). Stress, aggressive behaviour and fearful reactions can be reduced if animals are habituated to handling and human contact before other new and aversive procedures are carried out, such as branding, castrating or loading onto a trailer (Le Neindre et al. 1996).

Poor welfare is associated with the excessive use of electric prod devices. Warren et al. (2010a) measured the prod use occurring on 1161 trailer loads of cattle arriving at an Ontario slaughter facility. The levels of prod use in combination with the amount of shouting, banging on the trailer, the use of a paddle, cane or whip were used to assess the handling score. Scores were assessed as follows; 3 - the transporter did not use an electric prod or any of the other handling methods mentioned above, 2 - the transporter used the prod less than 5 times and used two or fewer of the other methods recorded, 1 - the transporter used an electric prod more than 4 times or used the other handling methods. Approximately half of the handlers had a score of 2 (52.7%) but many had a score of 3 (45.1%) and only 2.2% were assessed with a handling score of 1 (poor). Therefore, it can be assumed that many handlers use electric prods even though their use has been reported to adversely affect animal welfare (María et al. 2004). Grandin (2001) found that vocalization was increased substantially (from below 3% to 12-17%) when an electric prod was used on 95% or more of animals. Further, Grandin (2001) reported a reduction in vocalization by 5% when the voltage on the electric prod was lowered. Vocalization can be used as a tool to indicate if electric prods are being used in excess, handling is too aggressive, or if restrainers in the slaughter facility are too small (AMI 2012). Acceptable handling aids that can be used to move livestock are sorting boards, nylon flags, and rattle paddles (AMI 2012). When these alternative handling aids are used in a calm and encouraging fashion, the use of electric prods is normally unnecessary.

Equipment design facilitates proper handling techniques because cattle that are unwilling to move along a chute promote aggressive handling techniques such as yelling, hitting the animals or using an electric prod (Eldridge et al. 1986). Eldridge et al. (1986) and Grandin (2007) have suggested the following in order to ensure low stress handling; avoid corners that cause animals to change their direction more than 90 degrees because cattle perceive this as a "dead-end"; the use of solid sided fencing so that cattle aren't distracted by external features (like people, debris or shadows outside the chutes); and the use of curved chutes and stocking tubs, to take advantage of the natural behaviour of the cattle to circle the handler outside their flight zone. These design features are important for transported cattle when loaded, unloaded and in lairage at the slaughter facilities.

2.3.6 Loading and unloading

Loading, handling and the subsequent confinement on the trailer are usually a novel experience for livestock especially if extensively managed (as in the case of most beef cattle). Booth-McLean et al. (2007) reported that loading and unloading of cattle increase heart rate to a greater extent than the actual journey within the trailer. Further, María et al. (2004) scored cattle during loading and unloading according to events that could adversely affect their welfare and consequently cause stress. The detrimental events they recorded were: falls, reversals, aggressive bouts, mounting, balks, jumps, slips, eliminations, vocalizations and the use of electric prod. They found that the lowest cortisol, creatine phosphokinase and lactate levels (physiological indicators of physical activity and stress) were during loading procedures that combined a short duration with the least number of detrimental events (described above). Additionally, Warren et al. (2010b) documented that animal handling scores that reflected poorer handling (score of 3 on a 3-point scale) were associated with a higher occurrence of dark cutters. The qualities associated with this score were electric prod use, shouting, banging the trailer, side rails not used, animals hitting their back on the door, and the use of a paddle or cane. Their results indicated that quick, event-free loadings that used proper animal handling techniques resulted in the lowest stress on the animals. It follows from the aforementioned studies that suitable loading and unloading techniques are important for improving animal outcomes.

Timeliness in unloading will not only ensure that animals have access to feed, water and rest as soon as possible but it also reduces the amount of time the animals spend on a stationary vehicle, which can be subject to poor ventilation and rising temperature (Schwartzkopf-Genswein et al. 2012). When the American Meat Institute (AMI) audits a slaughter facility full recognition through their program is only awarded if unloading begins within 60 min of the animals' arrival (AMI 2012).

Facilities used for loading and unloading may also impact the efficiency and safety of the procedures. The maximum recommended loading ramp angle is 20-25° with cleats that have 20 cm of space between them to accommodate the cattle. Concrete ramps should have steps with a 10 cm rise and 30-45 cm tread length (Grandin 2007). Similarly Eldridge et al. (1986) recommended that loading ramps should be at least 75 cm wide for loading and wider for unloading. They also suggested that cattle would rather walk up steps than inclines; a 10 cm rise and 46 cm tread length could be used. These ramp dimensions should increase the ease of loading and reduce cases of cattle baulking during loading and unloading. Secure, nonslip footing also increases the ease of loading and unloading.

2.3.7 Noise and vocalization

Poor handling is often associated with actions causing loud noises such as yelling, banging on equipment, or slamming gates (Warren et al. 2010a; Grandin, 2007). Livestock species have very sensitive hearing (especially in the high frequency ranges; Grandin 2007). Noisy environments (gates clanging, people yelling and motors running) have been shown to increase stress and agitation. Waynert et al. (1999) found that cattle reacted more to humans shouting than to sounds of metal striking metal. Animals can be become habituated to constant noise but respond more to sudden, intermittent sounds (Grandin, 2001).

Vocalization of cattle has been associated with stress in livestock and has been used to identify handling and equipment problems (Grandin 2001; Grandin 1998). Vocalizations were reduced from 12.8 % to 0.8 % after equipment modifications in a slaughter plant, which included; reducing pressure of the neck restraint, reduction of electric prod use, reducing voltage of electric prods, illuminating dark entrances and adding false floors to conveyor restraints (Grandin 2001).

2.3.8 Stocking density

Stocking density during transport affects the stress, bruising, injury and death of livestock being transported. Tarrant et al. (1992) examined the effects of stocking density of steers on long-distance journeys (24 h). They found that a stocking density greater than 550 kg/m^2 (600 kg animals) increased carcass bruising, plasma cortisol and plasma creatine phosphokinase. They also reported that a high stocking density of 571 kg/m^2 for 600-kg animals was associated with an increased number of cattle going down and being unable to rise. At the same stocking density animals changed their standing orientation from perpendicular to the motion of the vehicle to parallel and their behaviour from footing shifts and changes in position to more serious struggles for footing and falls. Tarrant et al. (1992) concluded that this change in standing orientation and behaviour was due to cattle having reduced mobility and being less able to respond to truck movements when densely stocked. In addition, González et al. (2012d) reported that animals were more likely to die at unusually low ($\kappa < 0.015$ (κ = space allowance (m^2 / animal) / $BW^{0.667}$)) or high ($\kappa > 0.035$) space allowances particularly in the deck and belly compartments of a trailer. Eldridge et al. (1986) recommended that stocking densities be kept at 243 kg/m^2 (450 kg animals) in holding areas to facilitate low stress.

Recommended stocking densities for cattle transport in Canada are provided in Figure 2.2. Appropriate stocking densities depend on both the size and weight of the animals being transported. If shipping horned cattle the stocking density should be decreased by 6% below recommended densities for animals of that size (Fike et al. 2006).

2.3.9 Duration of transport

In North America, transport duration is especially important because of the long distances hauled and the long durations animals spend on the trailer. A recent study of approximately 50,000 cattle being transported to a large federally inspected beef slaughter plant in Ontario found that the average transport duration was 4.6 h, maximum transport duration was

68.3 h and the minimum transport duration was 0.3 h (Warren et al. 2010a). Another recent study of 290,866 cattle being transported for over 400 km reported that the average duration of transport was 15.9 h, with a maximum transport duration of 45 h (González et al. 2012b). Although the vast majority of recorded journey durations are within the regulated 52 h maximum they may not represent the entire trip length. Many animals are hauled to auction marts or assembly yards prior to being transported to a slaughter facility, which could serve to extend the total transport time.. Accurate records of total trip duration can be challenging to collect but are necessary to study the full impact of transport from the location of origin to the final destination.

González et al. (2012c) reported that travel longer than 30 h resulted in an increased likelihood of animals becoming non-ambulatory, lame, or dead as a consequence of the physical and physiological demands of standing for that length of time in transport conditions without feed and water. Malena et al. (2006) reported that at short travel distances (< 50 km) the mortality rate was 0.004 ± 0.002 % (out of 1.8 million animals) and at greater distances (> 300 km) the mortality rate increased to 0.024 % ± 0.027 %, however, the journeys over 300 km only made up 1.4 % of the total number of journeys.

Transport duration may also affect meat quality parameters however; the results have not been consistent across studies. María et al. (2003) found that transport duration (30 min compared to 6 h) had a slight effect on the meat texture but not on colour, pH or toughness, which are important qualities related to product quality. Villarroel et al. (2003) found that transport distance had no significant effect on meat tenderness or pH, 24 h after slaughter or meat colour. Similarly, Polkinghorne et al. (2013) reported no significant difference in eating quality (evaluated by sensory test), blood and urine parameters, ultimate pH, meat colour score, or live-weight between animals transported for 12, 24 or 36 h even with the addition of a 12-h rest period in the 24-h treatment group. In contrast, Tarrant et al. (1992) reported an increase in carcass pH after long journeys (24 h compared to 1 h) but the pH increase was relatively small (0.1-0.2 pH units) and occurred in only 4 of the 9 muscles tested. Puolanne et al. (1981) reported that the incidence of dark-cutting animals increased with increasing journey duration up to 5-7 h of transport, after which the incidence decreased slightly. Gallo et al. (2003) reported that with increased journey duration (up to 24 h) there were a higher proportion of dark cutting carcasses. The results of these studies indicate that there is a connection between transport duration and carcass quality but the extent and nature of the connection are unclear and dependent on many factors.

As indicated above, rest stops are required in Canada after 48 h of travel unless the final destination can be reached within 52 h. A rest stop will have varying degrees of benefit for the cattle depending upon the length of the rest period, the condition of the facilities and the quality of feed and water supply. If the conditions of the rest period aren't adequate then the rest stop may only prolong the journey duration instead of providing respite as intended (Grandin 1997; Polkinghorne et al. 2013).

2.3.10 Air quality and ventilation

Ventilation is important to maintain good air quality inside a livestock transporter. Poor air circulation, adverse air composition and temperature extremes can have a negative effect on livestock and serve to reduce welfare and increase stress (USDA 2005). Good ventilation can reduce the build-up of unfavorable gases (such as diesel fumes), odours and the animals' natural heat. It is common for trailers to have holes punched in the side to increase ventilation. The hole punches can be covered by sideboards to increase or decrease airflow in a trailer. Warren et al. (2010a) reported that increasing the sideboard usage in winter decreased the percentage of dark cutters presumably as a result of reducing cold stress. These same authors reported that reduced use of sideboards in summer or fall served to limit heat stress and increase airflow.

Air scoops (attachments for the side of the trailer that direct air into existing air inlets) have been tested as a way to increase ventilation in a livestock trailer. Although they improved the condition of the cattle by decreasing weight loss and dehydration they are not commonly used at this time (Giguere 2006).

2.3.11 Climate: internal (micro-climate) and external to the trailer

Cattle alter their behaviour (changing feed and water intake, changing posture and/or peripheral insulation) and physiology (sweating and panting) to counteract changes in their thermal environment. Transport restricts an animal's ability to change its behaviour, which makes it challenging for them to maintain thermal balance during transport if the thermal environment falls outside their thermal neutral zone (Mitchell et al. 2008). The temperature-humidity index (THI) accounts for the interaction between temperature and humidity and is commonly used to represent the internal or microclimate inside a trailer. If the THI falls outside the range of the livestock's thermal neutral zone then cold stress or heat stress, as well as compromised welfare, reduced meat quality and even death could result (Mitchell et al. 2008).

External environmental conditions, ventilation, stocking density, location within the trailer and trailer speed affect the microclimate cattle are exposed within a livestock trailer. Results from Greer et al. (2011) indicated that outside ambient temperature was correlated with internal trailer temperatures and that the temperature at animal height (measured by placing a sensor on ear tags) was on average 1.18 ° higher than the temperature measured on the ceiling of each trailer compartment. Journey duration was not correlated with internal ambient temperature during this study.

Temperature and season during transport have been found to have a number of effects on animal outcomes. González et al. (2012c) reported that if the average ambient temperature fell below -15 °C then the likelihood of cattle death increased and if the median ambient temperature rose above 30 °C then cases of non-ambulatory animals increased. They also reported that summer (June - September) had the greatest probability of animals becoming non-ambulatory and fall (September - December) had the greatest cases of deaths. However, it should be acknowledged that there were more finished cattle transported in summer (81.5 %) and more feeder cattle in fall, which could have affected the number of deaths during those seasons. Another study that occurred in the Czech Republic also reported different mortality levels between seasons (Malena et al. 2006). The highest mortality rate occurred in the summer months (July and August) with a mean temperature of 16.9 °C and 16.6 °C respectively, and in winter (January and February) with a mean ambient temperature of -2.6 °C and -0.8 °C respectively. Greer et al. (2011) reported that live weight loss (shrink) was positively correlated with the mean trailer THI. Animal outcomes reported on in these studies indicate that temperature and THI extremes can have detrimental effects on transported cattle.

2.3.12 Bedding

Bedding is beneficial for livestock during transport because it provides improved footing and protects the cattle from the metal floor commonly found in trailers. It also keeps the trailer cleaner by absorbing urine and feces during the journey (CARC 2001; Thrower 2009). It is recommended that the manure level stay below where the hoof meets the hairline which could be accomplished by adding bedding during long transport durations (AMI 2012). Bedding also has a role in improving air quality by absorbing ammonia. Powell et al. (2008) reported that the best type of bedding for absorbing moisture and ammonia was wood shavings. However, Thrower (2009) found that the majority (63.8 %) of truck drivers in Ontario use straw for bedding.

In Canada, it is a requirement to provide bedding during transport journeys longer than 12 h (or, if less than 12h, to have bedding, sand or footholds) but there is limited compliance with this regulation (CARC 2001; Department of Justice 2015a). González et al. (2012b) reported that only 22.7 % of all loads in Western Canada had bedding. In addition they found that drivers from companies that paid for the bedding had 97.5 % compliance with the regulation, indicating that cost is a deterrent for drivers. The most frequent use of bedding was for calves (67.4 %) and breeding cattle (75 %) likely because of their perceived more vulnerable state or high value of these classes of animals. Bedding was used most frequently in the summer (17.6 %) compared to the spring (32.7 %), fall (25.1 %) or winter (28.8 %). On the contrary, Thrower (2009) reported that 99.2 % of the loads of feeder and yearling cattle going to a slaughter facility in Ontario had bedding.

2.3.13 Trailer motion

2.3.13.1 Using GPS to measure trailer motion

Global positioning systems (GPS) are commonly used to continually and automatically measure the velocity and position of an object to which they are attached. They are a satellitebased navigational system that receives signals from at least four satellites to determine a position and velocity (Ta 2011). The GPS accuracy is affected by the receiver's position in relation to the satellites and interference from vegetation, structures, topography or atmospheric conditions (Wing 2005).

In many cattle studies, GPS systems have been used to determine the pattern of cattle movement within a pasture (Ungar et al. 2005). Studies have reported the accuracy of GPS to predict the receiver's position in a naturally vegetative area to be between 1.7 and 10 m (Wing 2005; Ganskopp and Johnson 2007). GPS is also used to determine the route and velocity of cattle transport trailers. Although 10 m may be an unacceptable amount of error to accurately determine cattle position within a pasture, it is adequate to predict the path of a cattle trailer because the area of concern is much larger in comparison (100's of km's compared to the size of an average pasture). Likely, cattle trailer position would be determined to a greater accuracy than 10 m because the trailers travel on open highways in Western Canada with little to no interference from vegetation or structures.

2.3.13.2 Using accelerometers to measure trailer motion

Acceleration is a vector quantity with a magnitude and a direction that measures the rate at which the velocity of something changes with time. The constant motion of a vehicle (velocity) isn't detrimental to animal welfare in terms of loss of balance, muscle fatigue or general discomfort; rather the change in velocity, or acceleration, are the determining factors (Randall 1992). Acceleration consists of static and dynamic (vibrations and shocks) movements. It has a magnitude (measured in m/s^2) and a frequency (measured in Hz), which can be altered by the suspension of the tractor and trailer, engine speed, transmission, ambient wind, weight and number of animals loaded, trailer construction, standing orientation of the animal, orientation of the animals over the wheels, driving style and road condition (Bradshaw et al. 1996; Randall, 1992; Perremans et al. 2001; Ruiz-de-la-Torre et al. 2001; Peeters et al. 2008; Gebresenbet et al. 2011).

Accelerometers have often been used to measure the amount of movement (acceleration) that occurs within a vehicle (Bradshaw et al. 1996). Some accelerometers have the capability of measuring in three orthogonal directions; vertical (up and down), lateral (side to side) and horizontal or longitudinal (front to back). Being able to measure acceleration in all three orthogonal directions is important because the directions of acceleration have differing impacts on animals in transport. Peeters et al (2008) established that the lateral direction of movement had the greatest impact on heart rate variability in pigs. They also found that driving style altered lateral and horizontal accelerations more than vertical accelerations.

The frequency of vibration is also an important factor in determining the impact of trailer motion. Low frequency vibration (2 Hz) causes greater displacement of the animal and results in loss of balance. Higher frequency vibrations (6-10 Hz) cause resonant frequency vibrations in the viscera and organs of animals and results in general discomfort and motion sickness especially in pigs (Perremans et al. 1998).

2.3.13.3 Effect of trailer movement on cattle

When animals are transported they are exposed to the motion of the vehicle in which they are being transported, which can have potentially detrimental effects on their welfare (Tarrant 1990; Bradshaw et al. 1996; Gebresenbet et al. 2011). It has been suggested that confinement on a moving vehicle is the most stressful part of transport (Tarrant 1990). Palme et al. (2000) measured fecal cortisol metabolite levels of 3 groups of cattle (transported, loaded and stationary, and not loaded). The group that wasn't loaded had cortisol levels that stayed relatively consistent throughout the experiment. The stationary group had cortisol levels that ranged from 2.1 to 6.8 times the basal levels. The transport group had cortisol levels that ranged from 5.5 to 39.1 times the basal levels. These values indicate that there is a certain amount of stress-associated with being loaded into a stationary transport trailer but even more stress results from a moving trailer. However, it has also been reported that, depending on the temperament of the animal and if it was raised intensively or extensively, handling and loading may be more stressful than the confinement on a moving vehicle (Grandin 2007). Studies have indicated that animals, given enough time, will calm down or adapt to transport after loading (Bradshaw et al. 1996; Hall et al. 1998). Stephans et al. (1983) demonstrated that pigs exposed to simulated transport (vibration, noise and confinement) had initially raised heart rates, which declined as the transport progressed. Nonetheless there is adequate research to indicate that vehicle motion does have a significant impact on transported livestock.

Many studies have shown a correlation between physiological parameters and transport motion. Hall et al. (1998) found that salivary cortisol and heart rate of sheep were increased initially by vehicular motion if they were loosely stocked (0.41 m^2 per sheep) but not if they were tightly stocked (0.28 m^2 per sheep). When studying pigs, Perremans et al. (1998) found that the highest heart rate was at a frequency of vibration of 2 Hz and a magnitude of 3 m/s^2, while the lowest heart rates, after the control, were found at 18 Hz and 1 m/s^2. Perremans et al. (2001) found that ACTH and cortisol levels in pigs were increased by vibration. Bradshaw et al. (1996) reported that pigs and sheep had raised cortisol levels on rough journeys on gravel roads compared to smooth journeys on highways. Ruiz-de-la-Torre et al. (2001) had similar results that showed that sheep plasma cortisol and heart rate increased on journeys over rough gravel roads compared to journeys on smooth highways. In contrast, Peeters et al. (2008) reported that salivary cortisol was lowest in animals that were transported in a "wild" driving style (higher accelerations) but they suggested that their results were probably due to the shorter duration of the wild-style journey.

Animal behaviour can also be affected by transport motion. Bradshaw et al. (1996) reported that both sheep and pigs lie down less on rough journeys compared to smooth journeys even though they would normally spend a significant amount of time lying. Peeters et al. (2008) and Perremans et al. (2001) also reported that pigs stood more on journeys with greater accelerations. It has also been reported that animals will stand in a specific orientation to improve balance and stability (Tarrant 1990). Cattle have been found to prefer standing parallel or perpendicular to the direction of motion (Tarrant 1990; Winker et al. 2003). Gebresenbet et al. (2011) reported that animals facing in the perpendicular direction experienced lower horizontal and vertical accelerations than animals standing in the parallel orientation (as measured with accelerometers).

The driver has a significant impact on the motion the animals will experience while being transported (Peeters et al. 2008). Tarrant (1990) suggested that cattle will often lose their balance during transport but are able to shift their weight in response and remain standing. If the driving event to which the cattle are exposed is too severe however they may become fatigued or even go down and are unable to rise. Tarrant (1990) found that 75 % of loss of balance occurred during cornering and braking or when two driving events occurred at once (for example braking and gear changing). González et al. (2012c) reported that with increasing driver experience (6 years or more), there was a decreased total proportion of compromised animals. Further, Warren et al. (2010b) reported that the prevalence of dark cutting decreased as the number of years of livestock trucking experience increased and if the driver had taken a livestock-hauling course. The effect of the driver is most likely due to their ability to manoeuver the trailer with minimal shocks and jolts in combination with their handling and loading skills (Schwartzkopf-Genswein et al. 2012). The COPT recognizes that driver training and experience is important to provide smoother, safer journeys. The recommendations of the COPT are in agreement with the international standards set by the OIE (2015) that state, "drivers should utilize smooth, defensive driving techniques, without sudden turns or stops, to minimize uncontrolled movements of the animals." It's important that drivers are encouraged to follow recommended driving techniques, drive carefully and take part in a driver-training course in order to provide the best transport conditions possible.

Currently there is a lack of relevant research pertaining to transport motion affects on cattle in Canada. Most of the prior research has taken place in Europe where they have different transporters and conditions of transport than in Canada (Stephans et al. 1983; Tarrant 1990; Randall 1992; Bradshaw et al. 1996; Perremans et al. 1998; Hall et al. 1998; Perremans et al. 2001; Ruiz-De-La-Torre et al. 2001; Wikner et al. 2003; Peeters et al. 2008; Gebresenbet et al. 2011). Along with being geographically inapplicable, this research has mostly been focused on sheep and pigs but not on cattle (Stephens et al. 1983; Bradshaw et al. 1996; Perremans et al. 1998; Hall et al. 1998; Perremans et al. 2001; Ruiz-De-La-Torre et al. 2001; Peeters et al. 2008). Although there is an abundance of information available regarding the effect of transporter motion on animals, it is of little value when trying to determine the effects of transport motion on cattle in Canadian conditions transported on the standard North American double decker tractor-trailer (González et al. 2012b). Further research is required in Canada to complement and validate research conducted in other countries.

2.4 NON-INVASIVE METHODS OF EVALUATING ANIMAL CONDITION

Condition is defined in the Merriam-Webster dictionary (2012) as a, "state of being," and, "a state of physical fitness or readiness for use." Animal condition therefore applies to both the psychological state of the animal and the physical condition of the animal. Animal condition scores quantify and/or qualify body condition, general condition (fitness, lameness and udder condition), and temperament and assess cattle reaction to (un)loading so that the scores can be easily compared and analyzed.

Loading and unloading scores can be considered types of animal condition scores because they often combine behavioural aspects, such as speed of entering or exiting the trailer and vocalization with the physical ability to maneuver the loading or unloading ramp (María et al. 2004; Warren et al. 2010a). It should be noted that loading and unloading scores often involve a handler score, which cannot be considered part of the animal's condition even though the handling can affect animal condition. Unloading and loading scores will be discussed in this section but the handling portion of the scores will be discussed along with the other factors affecting the welfare of the cattle.

Animal condition scores are an important way of assessing the ability of an animal to withstand the stress and challenges that transport entails. The animals condition before and after transport can be compared in order to characterize the effects of transport. Physical animal condition scores and behavioural scores are excellent assessment tools because they can be non-invasive (visual). These attributes make them suitable for commercial studies in which it may be difficult to physically assess the animals. However, when using non-invasive methods of evaluation it's imperative that a single observer takes the measurements in order to increase consistency and decrease bias.

2.4.1 General condition scoring

The first key to successfully general condition scoring cattle is knowledge of the assessment criteria. An animal in generally good condition is one that is not lame, compromised and has no udder issues (in the case of cows). Being able to determine if an animal has good general condition is the first step in deciding if an animal should or should not be transported and how the transport will physically affect it.

Another key factor in good general condition scoring for research purposes is determining the fitness of cattle before and after they are transported so that any deterioration in condition during the journey can be accounted for. In some studies it is impractical for the condition prior to transport to be assessed (González et al. 2012b; Warren et al. 2010a). In these studies only the final condition of the animal is known and it is difficult to discern whether poor fitness was caused by the transport or if the animals had poor fitness prior to being loaded.

Animals are considered compromised if they are in poor fitness, non-ambulatory, have a severe injury, fatigued, heat stressed or close to calving (AMI 2012). These types of cattle should not be loaded for transport. A non-ambulatory animal is one that refuses to rise, is unable to stand unaided or is unable to bear weight on two of its legs. Severe injuries include but are not limited to; broken legs, gashes, cuts and prolapses. Fatigued cattle will exhibit open-mouthed panting and will be reluctant to move. In Canada the occurrence of non-ambulatory cattle arriving at a slaughter facility is relatively low: 0.022% in Alberta (González et al. 2012b) and 0.002% in Ontario (Warren et al. 2010a).

Lameness is another factor in determining the general condition score of an animal. There are a number of different ways of defining the stages of lameness. Veterinarians, when examining cattle for lameness, will use both subjective visual evaluations and physical examination (Desrochers et al. 2001). Physical examination, however, isn't practical in a commercial transport situation, therefore transport researchers use a visual evaluation of lameness similar to the one described by Desrochers et al. (2001) or they don't consider the extent of lameness, only the presence or absence (Warren et al. 2010a; González et al. 2012c). The evaluation method described by Desrochers et al. (2001) uses a 5-point scale beginning with zero, which indicates no gait abnormality. A score of one indicates a mild, intermittent gait asymmetry; a score of two indicates a moderate, consistent gait asymmetry; a score of three indicates a severe gait abnormality and a score of four is a non-ambulatory animal. Lameness in Canada has been recorded at the slaughter facility in 0.011% of cattle in one study (González et al. 2012b) and 0.158% of cattle in another study (Warren et al. 2010a).

When cull cows (dairy or beef) are transported it is important to consider the state of their udder as a welfare concern. The AMI (2012) considers an udder of poor condition to be one that descends more than 7.6 cm below the hock, if the udder makes it difficult for the cow to move as it pushes against the rear legs or if it is distended to the point of causing pain or distress. All of these factors (compromised condition, lameness, and udder score) should be used to determine the general condition of an animal, which animals to transport, how they will be transported and to the transport destination. These factors can also be used by researchers to determine how transport affects cattle condition.

2.4.2 Body condition scores

The measurement of body condition scores (BCS) is a subjective method of evaluating the fat and muscle stores of an animal that are a result of their previous nutritional status. The body condition (BC) of an animal can indicate how effectively they will cope with stress because it refers to the level of metabolizable energy stored as fat and muscle. There are two main scales that are used to evaluate body condition. The current Canadian system uses a scale of 1 to 5 and the current American system is a scale of 1 to 9 (AAFRD 2006). The benefit of collecting BCS is that they are relatively easy to understand, it is a cost effective method, they are rapid to collect, sufficiently accurate, unaffected by body weight, and can be collected visually (noninvasively). There are numerous informational fact sheets produced by government organizations and universities that provide valuable information on how to use BCS (Rodenburg 2000; AAFRD 2006; Parish et al. 2008; Eversole et al. 2009). Recently, the BCRC released an interactive tool to help producers BC score and the relative costs of production at a variety of BCS (BCRC 2015a).

Usually BCS are assessed by palpating the areas of interest and by visual appraisal. Palpating is the preferred method because a full hair coat can hide animal condition. That being said, many producers prefer to visually inspect large numbers of free moving animals (especially with extensively managed animals). Edmonson et al. (1988) developed a comprehensive chart that depicts the characteristics of cattle that fall within each body condition category. These locations are depicted in Figure 2.3 and fall into three main areas: the loin, pelvis and tail-head.

Age, breed and frame size must be considered when doing a BCS because some breeds naturally have different fat deposition patterns and older cattle usually carry less fat over the back than younger cattle.

In general, BCS is used to manage herd feeding programs and fertility. There are a number of studies that have measured how an animal's BC can affect its production, growth and reproduction (Lalman et al. 1997; Morrison et al. 1999). Other studies have considered the nutritional requirements to either maintain or change BCS (Klosterman et al. 1968; Tennant et al. 2002; Roche et al. 2006). Generally, animals with a low BC, for their stage of production, may have difficulty rebreeding, poor performance and raise calves with low vigour. Animals with a high BC will be expensive to feed, may fail to cycle or may have calving problems like dystocia (AAFRD 2006; Eversole et al. 2009). BC scoring should also be considered when transporting animals because it will likely affect how an animal is able to cope on a long journey. An animal with low BC may be unable to mobilize energy for long journeys without feed and water and therefore be more detrimentally affected (Grandin 2007).

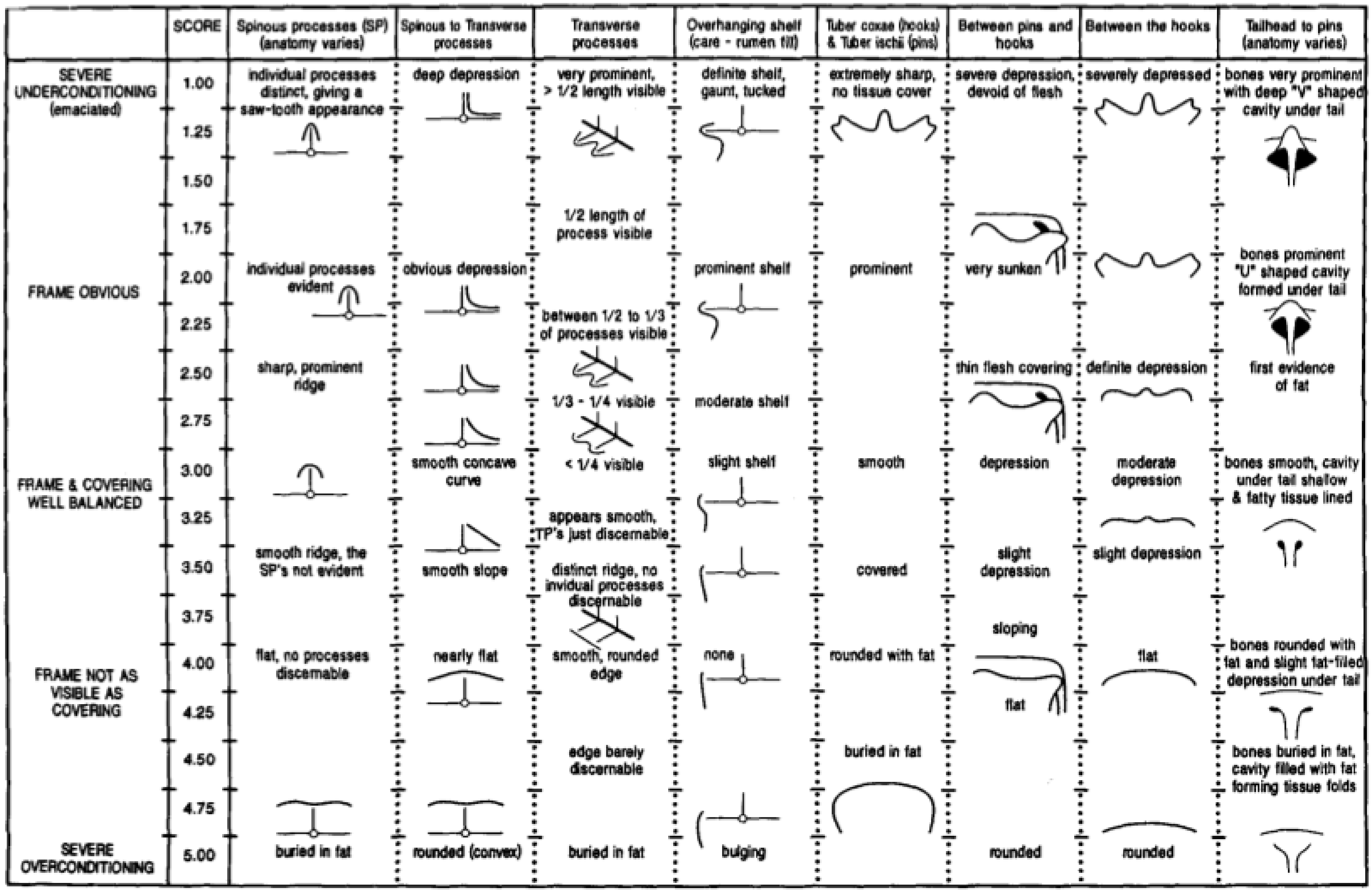

Figure 2.3 Body condition scoring chart. Source: Edmonson et al. (1988)

2.4.3 Loading and unloading scores

The conditions of transport affect the physical, physiological and psychological state of the animal when it leaves the trailer (Trunkfield et al. 1990). The cattle's behaviour (or the psychological state of the cattle as well as the physical state) when entering or leaving the trailer has been used to assess handling techniques, facility design and conditions of transport (Grandin, 2007). The behavioural assessment of cattle entering and exiting the trailer has been designated as the loading and unloading scores.

One of the most widely used criteria for (un)loading scores is located in the American Meat Institute's Animal Handling Audit Guidelines (AMI 2012). One of the criteria of the audit relates to the frequency of slips and falls. Falls are defined as, "when an animal loses an upright position suddenly in which a part of the body other than the limbs touches the ground." A slip is when a knee or hock touches the ground.

María et al. (2004) designed a method of evaluating loading and unloading behaviour in order to assess the welfare of the animals being transported. This method of evaluation is desirable because it is non-invasive and relatively simple. It is based on a six-point scale of behavioural events combined with the time taken to unload the animal. A number of unloading duration levels are represented by one of the following letters: T, R, A, N and S. The letter scores and the numbered behavioural scores were combined to create the final score. The behavioural events recorded were falls, reversals, aggression, mounting, balks, jumps, slips, eliminations and vocalization. In a study with feedlot cattle, unloading time ranged between 1 and 11 min and on average 8.0 behavioural events occurred during that time. Most of the behavioural events that occurred were slips, turns and jumps. They were able to validate this method of scoring unloading by correlating the unloading scores with cortisol, creatine phosphokinase and lactate levels. The results indicated that quick loading and unloading times with relatively few behavioural events were associated with lower levels of stress (cortisol, creatine phosphokinase and lactate levels). As this study demonstrated, auditing of unloading can provide useful information pertaining to the welfare of cattle.

Unloading speed is an important aspect of (un)loading scores. Warren et al. (2010a) scored the cattle as they were unloaded from trailers using a three-point scale. The scores were averaged for an entire trailer load of cattle. The 1 on the scale represented a walk, the 2 a trot and the 3 a run. Their results indicated that 13.7% of cattle walked off the trailer, 76.6% trotted off the trailer and 9.7% ran off the trailer.

2.4.4 Temperament scores

The temperament of an animal will influence its reaction to novel experiences such as transport and handling and therefore it is imperative to qualify and/or quantify the temperament of animals before they are transported, in order to predict the severity of their reaction to the experience. Animals that are flightier, more nervous or aggressive may be prone to increased levels of stress and result in more cases of meat quality issues such as bruising and increased toughness (Gruber et al. 2010; Stockman et al. 2012). Methods that have already been developed to characterize temperament are: response to handling (Le Neindre et al. 1995), response to entering and confinement in a squeeze chute (Voisinet et al. 1997; BFI, 2002; Baszczak et al. 2006; Gruber et al. 2010; Stockman et al. 2012), response to the presence of a human (Gruber et al. 2010), entry force into a squeeze chute (Baszczak et al. 2006) and flight speed (Stockman et al. 2012).

The Beef Improvement Federation (BFI) developed a scoring system for evaluating cattle temperament based on a 6-point scale. The scores range from 1, a mild animal that stands and moves slowly, to 6 an extremely aggressive animal that may attack or thrash around wildly. Similarly, Gruber et al (2010) used an adapted version of this scoring system to measure the behavioural signs of pre-slaughter stress and its effects on muscle tenderness. They adapted the scoring system to a 5 - point scale and used a 15-cm semi-structured, continuous line scale to record measurements. Alternatively, Baszczak et al. (2006) scored cattle on the amount of force necessary to encourage an animal into a squeeze chute. A score of 1 meant no physical contact was necessary where as a score of 4 was assigned if the animal needed several taps with an electric prod. Baszczak et al. (2006) also measured the behaviour of the animals in the chute with a 3 - point scale in which 1 = calm, 2 = restless and 3 = struggling. A recent study by Stockman et al. (2012) measured chute agitation scores (confined without head restraint in a squeeze chute), tension scores and flight speed. The chute agitation scores were measured with a 5-point scale with similar criteria to the BFI scoring system. The tension score was a measure of the animal's body tension. A score of 1 represents an animal that is comfortable in a squeeze chute, not tense and with little movement. A score of 4, on the other hand, is an animal with a tense body, shows signs of fear, and is moving or shaking. The flight speed of the animals is also measured as the time it takes an animal to travel 1.7-2.2 m from the chute in s. They then compared these temperament scores which resulted in a qualitative behavioural assessment Interestingly, the temperament scores of the cattle determined using chute agitation scores, tension scores and flight speed did not correlate to the later behavioural scores obtained using qualitative behavioural assessments. This indicates that a definitive temperament score can be difficult to achieve because of the subjectivity in scoring and the variety of ways that temperament can be physically displayed. That being said, temperament information can give valuable insight regarding animal response to a stressful situation and the effect their response can have on subsequent meat quality.

In summary, non-invasive methods of evaluating cattle are effective in describing their psychological and physical states. The general condition, body condition, temperament and (un) loading score of cattle can help transporters and researchers determine how individuals or groups of animals will respond to transport. They can also use the cattle's reactions to gauge the effectiveness of certain transport techniques and environmental conditions.

2.5 OUTCOMES OF VARIOUS TRANSPORT CONDITIONS

2.5.1 Carcass quality

Carcass quality is of prime importance to producers, processors and consumers in terms of meat safety, meat quality, economics and the efficiency of the beef-production system. Quality in slaughtered cattle is determined by the level of pathogen spreading, animal shrink, dark firm dry (DFD) meat, bruising and the carcass eating quality in terms of marbling, pH, color defects and water holding capacity (Schwartzkopf-Genswein et al. 2012). These factors are monitored by a number of national beef quality audits (NBQA) that have taken place throughout North America (NBQA 2011). Meat quality defects can be reduced through improved management strategies and research is used to determine which management strategies will be most effective.

2.5.1.1 Bruising

Bruising, an impact injury as a consequence of jostling, nudging, falling and bumping often occurs when improper handling techniques, poor facilities and poor road driving techniques are used. Most bruising occurs on the backs of cattle (Nanni Costa et al. 2006; LMAC 2010). A study by Vogel (2006) reported that 53% of bruising occurred in the round, 23% in the loin, 16% on the rib and 6 % in the chuck in cull cattle These bruises are likely caused by slamming gates into cattle, bumping into protruding objects (nails, exposed bolts, broken boards), bumping into other animals, or the chute or truck gates set too low causing the cattle to hit their backs (Grandin 2007; Huertas et al. 2010). The animal's path should have smooth surfaces especially between 28 and 52 inches from the floor in order to prevent bruising. Even if the path is totally clear they can still hurt each other when rushed or stressed. If animals do bump into each other more damage will be caused if the cattle have horns, even if they've been tipped (Grandin 2007). Vogel (2006) also found that cull cows have a higher prevalence of bruising. They speculate that this is the case because producers don't recognize the value in cull cows (especially if they are dairy animals) as readily as finished animals and therefore have less incentive to keep them in their best condition. Cull cows are often thinner and weaker (attributes which have been associated with bruising) than other slaughter animals (Personal communication 2015, Melinda German, General Manager, Manitoba Beef Producers).

Bruising not only affects the welfare of livestock but is also costly to the industry. The 2010 / 2011 Canadian NBQA found that bruising cost the Canadian industry $2.1 / head or $6.7 million total (for finished and non-finished animals combined) (NBQA 2013). The majority of the bruising in the 2010 / 2011 audit was minor (73.3 %) but there was some that was major, resulting in 0.68 – 1.36 kg of trim (23.9%) or over 1.36 kg of trim (3.8%). Although there was a reduction from 50% to 34% from the earlier NBQA in 1999, this value can be further reduced by better animal management prior to slaughter. This is also true in the US; their NBQA in 2005 reported that 25.8 % of carcasses had one bruise, and 9.4% of cattle had more than one bruise (Garcia 2008).

During transport, there are ample opportunities for animals to bruise themselves on each other, on the trailer and on the handling facilities (Strappini et al. 2012). Rapid acceleration, high stocking density and poor handling have been connected to an increased amount of bruising in cattle (Tarrant et al. 1992; Grandin 2007). Unloading and loading have been found to cause up to two-thirds of bruising associated with transport (Vogel 2006). This is likely associated with handling techniques. If cattle are rushed into trailers they will be more likely to balk, fall, hit the edges of openings and bump into each other. The driver's skill and road conditions also affect bruising. According to Vogel (2006) truckers should avoid, "roads that have numerous curves and bends, roads that course over hills and mountains, and sudden stops, fast starts and sharp turns that predispose to falling and injury." Training truck drivers and handlers how to use low-stress handling techniques and to maneuver a trailer has been shown as an effective way to improve animal welfare and reduce bruising (Vogel 2006; Grandin 2007).

2.5.1.2 Yield and quality grading

There are a number of ways to market cattle including live weight, dressed weight or grid pricing systems. The grid system has been growing in popularity because of its advantage in pricing carcasses according to their quality grade and yield grade (Schroeder et al. 1999). The grid works by giving premiums or discounts to cattle that fit into each grid section. Other discounts can also be given to B grade animals and dark cutters. The grid gives an incentive for producers to increase their carcass quality (Fournier 2002). In Canada there are 13 quality grades; Prime, AAA, AA, A, B1, B2, B3, B4, D1, D2, D3, D4 and E (Canada Beef Inc. 2012). The four highest quality grades (Prime, AAA, AA, A) represent approximately 88% of the graded beef (Canada Beef Inc. 2012). Table 2.1 describes the criteria for each of the quality grades. There are 3 yield grades in Canada; 1, 2, and 3, which are distinguished by their calculated lean meat yield. The lean meat yield is found using rib-eye length, rib-eye width and fat depth on the rib-eye. A yield grade of 1 has 59% or more lean meat, a yield grade of 2 has 54-58% lean meat and anything under 53% is classified as a yield grade of 3 (Canada Beef Inc. 2012).

Table 2.1 The quality grades of Canadian cattle (CBGA 2015)

THE QUALITY GRADES						
Grade	**Maturity (Age)**	**Muscling**	**Rib Eye Muscle**	**Marbling ***	**Fat Colour and Texture**	**Fat Measure**
CANADA PRIME	Youthful	Good to excellent with some deficiencies	Firm, bright red	Slightly abundant	Firm, white or amber	2 mm or more
CANADA A, AA, AAA	Youthful	Good to excellent with some deficiencies	Firm, bright red	A- trace AA - slight AAA - small	Firm, white or amber	2 mm or more
B1	Youthful	Good to excellent with some deficiencies	Firm, bright red	No requirement	Firm, white or amber	Less than 2 mm
B2	Youthful	Deficient to excellent	Bright red	No requirement	Yellow	No requirement
B3	Youthful	Deficient to good	Bright red	No requirement	White or amber	No requirement
B4	Youthful	Deficient to excellent	Dark red	No requirement	No requirement	No requirement
D1	Mature	Excellent	No requirement	No requirement	Firm, white or amber	Less than 15 mm
D2	Mature	Medium to excellent	No requirement	No requirement	White to yellow	Less than 15 mm
D3	Mature	Deficient	No requirement	No requirement	No requirement	Less than 15 mm
D4	Mature	Deficient to excellent	No requirement	No requirement	No requirement	15 mm or more
E	Youthful or mature	Pronounced masculinity				

***MARBLING** The assessment of marbling is based on the average amount, size and distribution of fat particles or deposits in the rib eye. Canadian beef carcass grading utilizes only four of the nine recognized levels of marbling from the USDA marbling standards. Listed in order of increased marbling content the nine levels are: Traces, **Slight**, **Small**, *Modest*, *Moderate*, **Slightly Abundant**, *Moderately Abundant*, *Abundant* and *Very Abundant*.

The Canadian NBQA in 2010/11 found that 1.2 % of carcasses were prime, 52.5 % AAA, 43.4 % AA, and 2.8 % A, which was an improvement from the 1998 NBQA (NQBA 2013). The average yield in 2010/11 was 58.7 % for steers and heifers. The 2005 NBQA in the US found that the average quality grade was Select (equivalent to Canada AA) and the average yield grade was 2.9 out of 5 (See Table 2.2 for a comparison of US and Canadian quality grades) (Garcia et al. 2008). The distribution of quality grades in the US were: 2.6 % Prime, 51.9 % Choice, 40.2 % Select, 4.4 % Standard, 0.7 % Commercial and 0.3 % Utility.

Table 2.2 Comparison of Canadian and US beef quality grades (Canada Beef Inc. 2015)

GRADE	MARBLING*	MATURITY**	MEAT COLOR	FAT COLOR	MUSCLING	MEAT TEXTURE*
CANADA						
Prime	Slightly abundant	Youthful	Bright red only	No yellow fat permitted	Good muscling or better	Firm only
AAA	Small	Youthful	Bright red only	No yellow fat permitted	Good muscling or better	Firm only
AA	Slight	Youthful	Bright red only	No yellow fat permitted	Good muscling or better	Firm only
A	Trace	Youthful	Bright red only	No yellow fat permitted	Good muscling or better	Firm only
UNITED STATES* **						
Prime	Slightly abundant	Maturity class A & B	Light red	Yellow fat permitted	No minimum requirement	Moderately firm
Choice	Small	Maturity class A & B	Dark-cutters permitted	Yellow fat permitted	No minimum requirement	Slightly soft
Select	Slight	Maturity class A	Dark-cutters permitted	Yellow fat permitted	No minimum requirement	Moderately soft
Standard	Practically devoid	Maturity class A & B	Dark-cutters permitted	Yellow fat permitted	No minimum requirement	Soft

* Minimum marbling and meat texture permitted for quality grade class. ** Maturity categories reflect domestic requirements. *** Standards as of June 2008.

2.5.1.3 Dark cutting

Dark- cutting meat (commonly known DFD)) is a meat quality defect that is a continual and increasing problem in the beef industry that results in lower carcass quality grades.

The 2010 / 2011 Canadian NBQA reported that 1.28 % of all youthful cattle were dark cutters which was an increase from the previous audit in 1998/99, which reported 0.84 % dark cutters. In the US 1.9 % of carcasses were dark cutters in 2005 (Garcia et al. 2008). If a carcass is dark cutting in Canada it will be automatically lowered to the B4 grade whereas in the US the carcasses are lowered by a part of a grade or up to a full grade but remain in the Choice, Select or Standard categories (Canada Beef Inc. 2012).

Dark-cutting meat is caused by glycogen depletion in the muscle due to high muscle exertion with low nutrient intake. When glycogen is broken down for energy it results in a lactic acid by-product. The lactic acid causes the pH to reach the correct level post-mortem. With reduced glycogen levels caused by transport fatigue, stress and restricted feed intake, the lactic acid is not produced and therefore the meat doesn't reach the desired pH level of approximately 5.5 - 5.7 (Warren et al. 2010b). The result of the increased pH (approximately 6.0) is denatured proteins in the meat, which causes dark purplish red to black colored lean meat visible during carcass evaluation. The meat is also dry and often sticky on the lean surface because it acts like a sponge, absorbing water (Miller 2007).

Long-haul transport has been connected to increased probability of dark cutting (Tarrant et al. 1992) presumably associated with accompanying stress and fatigue. A study conducted in Ontario also found that ventilation, sex, number of years of driver livestock-trucking experience, origin of the cattle, lairage, cattle unloading speed score and driver training were risk factors for increased dark cutting meat (Warren et al. 2010b).

2.5.1.4 Animal shrink

Shrink or live weight loss is the weight loss associated with processing, transporting and marketing of cattle. Shrink is caused by stress as well as FWD that occurs during these events. Even though cattle consume approximately 4 % of their body weight daily they have relatively small net changes in body weight on a regular basis because they are constantly fermenting and metabolizing feed and excreting wastes (Hogan et al. 2007).

Fill shrink or excretory shrink is the weight lost by cattle as urine and feces (Richardson 2005). Fill shrink occurs during the first 24 h of FWD (usually this happens due to transport) but the majority of the loss occurs in the first 12 h (Hogan et al. 2007). Knowles et al. (1999) found that 70 % of weight loss occurred in the first 14 h of transport, 89 % in the first 21 h and 95 % within 26 h. They also reported an average of 8 % loss in live weight of cattle transported for 31 h.

Tissue shrink, on the other hand, is the loss of fluid from the body tissues (dehydration) and can be exacerbated by stress from transport and handling. It usually occurs after a longer period of time (approximately 24 h) or after the animal has lost at least 6 % of its body weight and will be an average loss of 0.75 % of body weight after that (Tarrant et al. 1992; Richardson, 2005). In North America only 5 % of long-haul journeys are over 30 h and most are closer to the average of 15.9 ± 6.3 h (González et al. 2012b). The mean shrink found by González et al. (2012a) during long-haul journeys was 7.9 % of body weight (above the 6 % threshold in which body weight loss switches to tissue loss), which would indicate that a number of animals experience tissue shrink.

Since animals are not supplied with feed or water during regular North American transport there is a significant impact on shrink. Shrink is affected by a number of different elements of transport for example; travel distance, ambient temperature, driver training, prior condition, compartment in the trailer and origin. In Canada, the average reported length of a long distance journey (> 400 km) was 15.9 ± 6.3 h and the maximum journey duration was 45 h (González et al. 2012b). Both long-haul and short-haul journeys have associated shrink losses but the most substantial losses occur on journeys of a longer duration. For example, calves transported for 15 h had higher weight loss (14.6 kg and 23.6 kg) than calves transported for 2.7 h (7.2 kg and 9.2 kg) (Schwartzkopf-Genswein et al. 2007). Similarly Kent et al. (1986) found that calves transported for 18 h had an average weight loss of 2.95 kg while the average weight loss of calves transported for 6 h was 1.95 kg. González et al. (2012a) also confirmed the positive relationship between journey distance and shrink. In fact they found a multiplicative increase in shrink when both the journey duration and ambient temperatures on a journey were greater. The relationship between ambient temperature, journey duration and shrink was also established by Greer et al. (2011). Another factor influencing cattle shrink is driver experience and ability. Drivers with more experience hauling livestock (> 6 years) had lower shrink ($P < 0.05$) in the cattle they hauled (González et al. 2012a). The type of animal also influences the amount of shrink. In general, finished cattle have the least amount of shrink ($P < 0.05$), followed by feeder cattle, calves and cull cattle (González et al. 2012a). Location of origin can also affect shrink; cattle transported directly from feed yard to slaughter rather than from an auction mart will have less shrink ($P < 0.001$) (González et al. 2012a). Greer et al. (2011) also reported that the greatest shrink (3.51 %) was found in the nose compartment of a trailer compared to the other compartments. The next highest shrink was 3.19 % in the deck.

Shrink is an important factor when considering the effects of transport on an animal because it not only affects the live weight of the animal but also its carcass quality. It has been reported that FWD for 48 h will cause a carcass weight decrease from 278.8 kg to 261.9 kg, a lower yield score and increased muscle pH, darker meat color and muscle toughness (Jones et al. 1990).

There are many events in an animal's life that could affect the quality of its carcass. Transport is an event that occurs very close to the time of slaughter and it is therefore the perfect candidate to influence carcass quality. Transport involves many novel and potentially stressful or harmful experiences that could cause the carcass quality defects discussed above. Carcass quality defects indicate that economic losses are being absorbed by the cattle industry. Therefore, improvements during transport could decrease costs associated with carcass quality issues and increase animal welfare. These improvements would benefit producers, processors and consumers.

2.5.2 Bovine respiratory disease

Transport stress has been associated with suppressed immune systems and subsequent disease occurrence in feedlot cattle post-transport (Grandin 2007). It is widely reported that bovine respiratory disease (BRD), commonly known as shipping fever, is the most costly and widespread disease in the feedlot industry (Fike and Spire 2006; Smith 1998; Snowder et al. 2006). A study completed in the US, which collected data from 18,112 calves at feedlots, reported that 97.4% of the feedlots had an overall incidence of BRD of 14.4 % (Snowder et al. 2006).

Bovine respiratory disease is caused by infection from one or more microbial agents, such as viruses (infectious bovine rhinotracheitis, bovine viral diarrhea, bovine respiratory syncytial, and parainfluenza type3), bacteria's (*Mannheimia haemolytica, Pasteurella multocida, Haemophilus somnus*) and mycoplasmas (Snowder et al. 2006). These microbes are able to successfully infect an animal when it has been exposed to one or more environmental stressors including transport stress, is in a susceptible immunological state and has been exposed to BRD-causing pathogens (Cusack et al. 2003).

Immune suppression, which can result from transport stress, can predispose an animal to BRD infection (Stanger et al. 2005). The standard immune response to pathogen assault is to increase the production of white blood cells such as lymphocytes and neutrophils. Elevated cortisol reduces interleukin 2 production, which is a signaling molecule that stimulates the production of lymphocytes (Blecha and Baker 1986). Cortisol therefore has the effect of decreasing the effectiveness of white blood cells in defense against pathogens. Kent et al. (1986) noted increased plasma cortisol levels, increased neutrophil levels and decreased lymphocyte levels in calves transported 6 h and 18 h. Blecha et al. (1984), on the contrary, reported only a suppressed lymphocyte blastogenic response ($P < 0.05$) after steers were shipped 700 km without a significant increase in plasma cortisol and with raised levels of lymphocytes ($P < 0.05$) and neutrophils ($P < 0.01$).

Therefore, in order to reduce the occurrence and costly effects of BRD it is important to transport healthy, vaccinated cattle using low-stress transport techniques and minimizing their exposure to pathogens (Fike and Spire 2006).

2.6 ECONOMIC IMPACT OF TRANSPORT CONDITIONS

2.6.1 Costs associated with current transport conditions

Improving animal welfare during transport requires investment but that investment can be offset by the reduction in animal and carcass losses. The reduction in losses should encourage the continued improvement in transport conditions.

Losses related to transport occur due to bruising, shrink, lameness, dead animals, poor carcass quality and shipping fever. Although studies have indicated that a relatively low % of animals (0.045% of 290,866 cattle studied) become compromised during journeys on trailers in western Canada (González et al. 2012c), it can result in large costs to the industry and should be considered.

Costs associated with reduced carcass quality, shrink and shipping fever have been reported as significant to the cattle industry. Warren et al. (2010b) estimated losses of $0.55 / kg in dark cutting carcasses resulting in a $200 total loss per 365-kg carcass. The NBQA (2011) reported 1.28% of youthful cattle had DFD meat resulting in substantial losses. Bruising cost the Canadian cattle industry $2.1 / head or $6.7 million total in 2010 / 2011 because it often required the most expensive cuts of meat to be trimmed (Eldridge et al.1986; NBQA, 2011).

Shrink is associated with a significant monetary loss associated with it for producers and buyers alike. A mean loss in finished cattle of 4.9 % of body weight, a mean body weight of 655 kg after transport and a live weight price in Alberta in 2014 of 3.19 CAN $/kg (for finished steers), results in an average loss of $102.4 / animal, if they are marketed on a live weight basis (Canfax 2014; Canfax 2015; González et al. 2012a). Shrink costs both the producer and the processor money. To account for shrink a fee, commonly called pencil shrink and calculated as 5 % of the animal's body weight, is often subtracted from the market value of the cattle. This pencil shrink means that producers are being paid less for their product, whereas processors are affected by the actual carcass weight loss due to shrink. It would be in both parties best interest to reduce overall shrink rates.

The calculated costs in the NBQA due to dark cutting, bruising and shrink are not all caused by transport however; those associated with transport are significant. Economic losses associated with BRD can occur as a result of compromised immune systems from strenuous transport conditions (Grandin 2007). Industry costs associated with BRD are due to death and treatment and poor growth in animals recovering from the disease (Grandin 2007). In 2010, the highest percentage (26.5 %) of non-predator cattle death loss in US was caused by respiratory problems (NASS 2010). Between 1992 and 1995 in the US, losses were estimated at $0.19-0.35 per kg of a calf that was infected with BRD (Smith 1998). Loss of profit can also occur due to decreased meat quality in terms of colour, texture and keeping quality of meat (Eldridge et al. 1986).

2.6.2 Costs associated with improving transport conditions

Improving transport conditions can be costly due to investments needed in research, retrofitting old equipment and improving transport practices (e.g. adding bedding to the trailer). Research is a major industry investment but it is one of the few ways of validating the efficacy of changes in transport practices. Costs can be incurred by the transporter for improving or replacing old or outdated equipment and facilities, for example, adding air scoops to increase ventilation (Nicole 2006). Adding bedding to a trailer is an additional cost of approximately $30

– 70 per load, but it can improve the welfare of transported cattle (Schwartzkopf-Genswein et al. 2012). Finding the shortest route for a journey and using an appropriate stocking density are procedures that should be employed by transporters to support good animal welfare (Speer et al. 2001). Washing and disinfecting transport vehicles is costly but can reduce the transmission of pathogens (Fike et al. 2006). Although, these tactics can take time and money, they are important for ensuring quality cattle transport.

2.6.3 Strategies to mitigate losses associated with transport

It can often seem like the economic viability of the transport industry is in direct conflict with the improvement of animal welfare and conditions of transport (Fike et al. 2006; Grandin 2007). There is economic incentive for transporters to maximize the distance travelled at one time and the carrying capacity of a trailer in order to increase profit (Fike et al. 2006). The concept of maximizing tractor-trailer use to increase revenue, however, is misleading. Improving transport conditions for livestock can actually improve animal health, welfare and reduce losses associated with reduced carcass quality and yield, bruising, shrink, post-transport illness, and even death (Eldridge et al. 1986). A balance between animal welfare and economic concerns would increase the efficiency of the production chain and benefit the transporter, the animal (in terms of welfare) and the consumer.

2.6.3.1 Producer-initiated strategies

There are many contributors in the transport chain but it could be argued that producers have the most important role. The cattle's condition when they are loaded onto a trailer, which is in direct control of the producer, determines their ability to cope with the stresses associated with transport (Fike et al. 2006; Grandin 2007). The transport chain is only as effective as its weakest link and if the cattle are already in poor condition, non-ambulatory, diseased, or too young or too old for transport when they arrive to be loaded, losses will ensue even if the transport conditions are ideal. In a situation in which the transporter is forced to decide whether to load cattle that are of questionable condition the transporter has few, less than ideal, options. The transporter could: 1. refuse to load the cattle (at the risk of losing the producers business) 2. provide special care (at a cost to the transporter) or 3. transport the animal(s) even though losses would likely occur due to shrink, bruising and reduced carcass quality (Fike et al. 2006). Producers can aid transporters by making it a priority to supply healthy, well-conditioned animals for transport.

One way of confirming that cattle are prepared for transport is to feed them adequately before they are loaded. There have been many different feeding strategies advocated by researchers to reduce shrink, reduce illness and increase weight gain post-transport such as; feeding hay vs. concentrates or grazing, providing electrolytes, vitamins, antioxidants and antibiotics (Fike et al. 2006). Preparing calves for transport by pre-conditioning and the subsequent transition into a feedlot bunk feeding system have also been reported to be beneficial (Fike et al. 2006).

Some research has shown that there may be a benefit to on-farm direct marketing compared to traditional marketing through an auction mart. Mortality and cases of dark cutting in cattle were greater in animals that were loaded from an auction mart than direct from farm or feedlot (Warren et al. 2010b; González et al. 2012c). However, this could be partially attributed to the higher number of at-risk cattle (for example cull cows) sold by auction mart than by direct marketing. By loading cattle straight from a farm or feedlot the cattle are not exposed to the extra stress of being loaded, unloaded, run through a sales ring and likely mixed into different social groups at the sale barn. Producers choosing direct marketing could help to reduce losses in the transport chain associated with marketing through an auction mart.

One of the greatest challenges for the industry regarding transport welfare, is that producers are unable to see the consequences of their production methods and marketing decisions. However, there is a recent development that may increase producer accountability for losses; the Beef Infoxchange System (BIXS). This system allows beef producers access to specific individual animal data. The system uses each animal's RFID tag provided by the CCIA to exchange data between producers (cow-calf, backgrounder and feedlot) and processors. The exchanged information includes the animal's production, performance, health, genetic and carcass data. This information could be used to increase communication between all levels of beef production on an individual animal basis and by doing so increase the efficiencies throughout the entire system (CCA 2012). The BIXS system could help to increase producer accountability by keeping them informed and increasing their awareness of how each of their animals is performing after they leave the farm.

2.6.3.2 Transporter-initiated strategies

There are many techniques in which transporters can improve the conditions of transport and welfare of cattle including; following proper stocking densities; observing rest periods; using considerate driving techniques; maintaining careful handling; being aware of environmental conditions and methods of reducing their impact; and designing safe and effective facilities (Tarrant 1990; Fisher et al. 2009; Grandin 2007). The effect of transport on animal welfare is obviously quite complex and in order to understand and improve transport there needs to be dependable information available (Swanson et al. 2001). There is a need for relevant research, especially in Canada where there have been only a few studies completed under Canadian conditions (Schwartzkopf-Genswein et al. 2012). Concrete answers to transport issues are difficult to find because of the extensive variability in transport conditions and research results. Nonetheless, research that is current, geographically applicable and uses the latest technology (such as GPS, accelerometers, and environmental data loggers) will help facilitate good regulation and sound transport practices (Swanson et al. 2001; Doonan et al. 2008).

Best management practices resulting from research, training programs, recommended codes of practice and legislation should continue to be used (Speer et al. 2001). It is the transporters duty to ensure that these guidelines are learned and followed. The development of critical control points in transport could also help to improve the efficacy of training programs, legislation and recommended codes of practice (Speer et al. 2001). In terms of legislation, laws need to be detailed, relevant and enforced (Grandin 2007). Good regulations that are enforced not only ensure animal welfare but are also effective at promoting compliance. It is often tempting for transporters to load unfit animals or load too many animals onto their trailer because of economic incentives and producer pressure. Livestock haulers could be more confident in their decision not to load extra or unfit animals if they had solid research and regulation supporting their decision.

It is important that transport companies endorse the CLT course and use work incentives based on animal performance, not transport quantity, to encourage drivers to keep animal welfare a top priority. It is also important that drivers take advantage of the information available in the course to improve their cattle-hauling skills. It has been reported that drivers that have taken a training course have reduced animal loss after transport (Warren et al. 2010b; González et al. 2012a). The CLT program and work incentives can motivate drivers to improve their handling skills, driving skills, planning techniques and quality of equipment (Grandin 2007).

In addition to their role regarding animal welfare, transporters can also influence beef quality and safety. Trailer sanitation procedures are important as pathogens implicated in food safety issues (*Salmonella*, *Campylobacter* spp, and *E coli* O157:H7) as well as pathogens involved in BRD complex can be transferred in trailers (Beach et al. 2002; Fike et al. 2006). Barham et al. (2002) reported that *Salmonella* spp. shedding increased from 6 % on hides and 18 % in feces to 89 % on hides, 46 % in feces and 59 % on trailers, however, they reported no increase in *Escherichia coli* O157 and they suggested that cleaning and sanitizing the transport trailer could be a critical control point in reducing the prevalence of pathogens. Reicks et al (2007), nevertheless, reported that although there was an increase of salmonella and aerobic microorganisms on hides after transport, this was not related to the cleanliness of the trailer prior to transport.

The CARC (2001) state that commercial unloading facilities should have a facility to clean vehicles in all seasons and that cleaning and sanitizing are important in the prevention of disease spreading. Grandin (2008) suggests that cattle trailers should be cleaned out at least once a week but ideally after every load of cattle. There are no readily available Canadian statistics on the frequency of cleanout and sanitation of cattle transport vehicles but it is known that few trucking companies or processing plants have designated cleanout areas (Schwartzkopf-Genswein et al. 2012). In Kansas, many livestock haulers (84 %) do not wash their transport vehicles between each load of cattle and many wait longer than a week between washing. Very few (5 %) livestock haulers in Kansas use disinfectants when cleaning their trailers (Fike et al. 2006). There is clearly a lot of room for improvement in cattle trailer cleaning regimes that could increase biosecurity and cattle health in the transport sector of the cattle industry.

2.6.3.3 Processor-initiated strategies

Processors are the last link in the transport chain before the consumers receive the product. They have the responsibility of ensuring that all the hard work and effort of the producers and transporters is not lost during the final phase of production. They can accomplish this by providing proper unloading and lairage facilities and using humane handling and slaughter procedures (Grandin 2007). Quality auditing of processing plants can help to ensure that this is accomplished.

In the US vast improvements were made to the handling and slaughter methods in processing plants by the introduction of customer audits (Grandin 2000). The customers (for example McDonald’s and Burger King) required that the plants improve equipment, provide better training, and modify their facilities to fit the costumer’s standards or the customer would cease buying their product (Grandin 2007). In Canada, CFIA inspection and customer audits help to ensure that safe and humanely produced products are retailed (CFIA 2011). There is also a program called the Professional Animal Auditor Certification Organization (PAACO) that trains and certifies animal auditors that are actively auditing across Canada and the US (PAACO 2005). Auditing can be improved by making audits easy to understand and execute, making sure minimum standards are realistic, developing procedures to correct problems and by using 3rd party auditors such as PAACO (AMI, 2012). Processors can also help by requiring or encouraging transporters to take the CLT course or refusing to accept cattle that have been hauled in questionable conditions, which may help to improve transport procedures.

Communication is the most important factor for the producers, transporters, processors, researchers and law enforcers to consider when improving transport procedures. Training, supervision, and work incentives are important motivators that should be taken advantage of at all levels of industry (Miranda-de la Lama et al. 2012). Strategies to mitigate losses in the transport industry should consider economic concerns, scientific research and consumer's expectations of animal welfare standards (Doonan et al. 2008).

2.7 SUMMARY

Cattle transport is an essential link in the cattle production chain. Cattle are transported from their ranch-of-origin to sale barns, back-grounding operations, feedlots, and processing plants. Canadian federally inspected cattle processing plants have been continually consolidating in the past years, which requires cattle to be transported further than ever for processing. That is why now, more than ever, it is imperative that transport is accomplished with the utmost regard for animal welfare, safety and health.

Each aspect of transport should be considered, individually and as a contribution to the whole system, for improved transport strategies to be implemented. Transport factors include animal type, animal temperament, social groupings, animal management prior to transport, feed and water deprivation, handling, (un)loading, noise, stocking density, duration of transport, air quality, ventilation, internal and external trailer climate, bedding and trailer motion. These transport factors, if not managed properly, can have a detrimental effect on animal outcomes such as animal condition, health status and carcass quality. Carcass quality includes an assessment of shrink, bruising, yield, grade, dark cutting and meat qualities such as marbling, pH, color and water holding capacity. The detrimental animal outcomes mentioned above (such as bruising, shrink, dark cutting) can have a substantial cost to the industry and it is in everyone's best interest (producer, consumer, processor and transporter) to reduce the loss and improve the economic sustainability of the industry.

There are a number of strategies that can be implemented by producers, transporters and processors that will facilitate the improvement of the transport industry and mitigate losses caused by transport. Producers can use feeding strategies, cattle conditioning strategies, make suitable marketing decisions and use feedback from industry on animal outcomes as approaches for advancing the transport industry. Drivers should keep well-equipped, clean trailers, abide by the COPT and current legislation, and participate in training programs in order to improve their hauling skills. Transport companies influence the attitude and adherence of drivers regarding best management strategies. Finally, processors can use quality audits and adequate cattle handling facilities and procedures to keep the transport chain functioning optimally.

Communication is a key to gaining support of all industry members when a change needs to be made. It also aids in ensuring these changes are maintained and completed in a timely fashion. Research should be used to substantiate these changes to the industry and should be relevant to current industry practices. In that way industry can ensure that transport conditions will facilitate cattle health and welfare and promote a quality end-product for years to come.

3. MANUSCRIPT I: Use of accelerometers to assess trailer motion and its impact on carcass bruising in market cows during transport

3.1 ABSTRACT

Increased trailer motion, coupled with large accelerations and decelerations, have been associated with decreased carcass quality and increased stress indicators in cattle, sheep and hogs. However, motion of livestock trailers has not been measured in North-American cattle semi-trailers over long distances (> 1000 km). The objective of this study was to describe the acceleration within each of the 5 compartments of a cattle semi-trailer and to determine the relationship between trailer acceleration and bruising severity. The root mean square (rms) of acceleration was measured at a sampling rate of 200 Hz in 3 orthogonal axes; x (vertical), y (front to rear) and z (lateral; side to side) by rigidly clamping an accelerometer to the cross beam below each of the five compartments of 8 trailers transporting 330 animals from an assembly yard to a processing facility. Journeys ranged in duration from 780 min to 942 min. The number and severity of bruising were obtained prior to trimming for n = 291 carcasses and ranged from 0.38 to 12.75 and 0.38 to 14.88, respectively. Mean bruise number and severity per carcass was 4.52 ± 2.43 and 5.31 ± 2.84 respectively. The mean rms of acceleration for all trailers (31 accelerometers) was 1.01 ± 0.32 m/s^2, 0.72 ± 0.31 m/s^2, 0.97 ± 0.30 m/s^2 for the x, y and z axes, respectively. There were no significant relationships observed between bruising and acceleration. Extension and replication of this research is required to further understand the relationships between trailer motion, carcass bruising and overall animal welfare.

3.2 INTRODUCTION

The safety and welfare of market cows during transport is of particular concern to producers, transporters and processors due to the increased risk of death, injury or severe carcass defects compared to other cattle types such as feeder or finished cattle (Strappini et al. 2010; González et al. 2012c). A common carcass defect in market cows is bruising, which has long been associated with aggressive driving (quick starting and stopping, fast cornering and elevated trailer vibrations), among numerous other factors such as rough handling, protruding objects in handling facilities, slippery floors, horns, cattle temperament and improper space allowance (Tarrant 1990; National Beef Quality Audit (NBQA) 2013). Bruising not only causes substantial economic losses to the cattle industry but also contributes to reduced cow welfare (NBQA 2013; Strappini et al. 2013). If reducing overall trailer accelerations can mitigate bruising severity, it would substantiate training techniques that promote careful driving methods (slow turning, braking and accelerating) including those taught by the Canadian Livestock Transport Certification Program (CLT).

Measuring accelerations, in the form of shocks and jolts, is commonly accomplished using accelerometers. Most accelerometers on the market are expensive (>$1000), have to be wired directly to a data storage device or computer, or store data for only a short period of time at the sampling frequencies necessary for the nature of this research. In order to collect acceleration data on a commercial livestock transport trailer, this type of accelerometer was not practical given time limitations for installation and the inability to modify or run wires within a large number of trailers transporting cattle for long time periods. Therefore, a novel method of collecting acceleration data was necessary for this project.

In consideration of the factors stated above, the main contributions of this paper were designed to be; (1) the development of a practical method of measuring trailer acceleration using an affordable, self-contained sensor and techniques for further processing the resulting data; (2) to describe the range of accelerations cattle are exposed to on a typical North American cattle transport trailer during long journeys; and (3) to conduct a preliminary analysis of trailer acceleration and its effect on carcass bruising in market cows. The hypothesis of this study was that acceleration could be accurately measured using self-contained accelerometers attached to commercial trailers and that increased acceleration would result in increased carcass bruising.

3.3 MATERIALS AND METHODS

Data collection within this study was approved by the Animal Care and Use Committee of the Lethbridge Research Centre according to the guidelines established by the Canadian Council on Animal Care (CACC 2015). The research staff did not control direct handling and care of the animals in this study.

During March and April of 2013, sensors were attached to 8 commercial cattle trailers transporting market cows from southwestern Manitoba to central Alberta. The data used for analysis in this study were a subset of data collected during the study by Goldhawk et al. (2014d), however the accelerometer data are unique to the current paper. There were 329 cows and 1 bull transported within these trailers. Journey duration ranged from 780 to 942 min (13 to 15.7 h), beginning between 6:11 and 7:17 MST and ending between 19:21 and 22:59 MST. The beginning of the journey started when the first animal entered the trailer and ended when the last animal was unloaded from the trailer.

Class 8 tractor-trailers, constructed of aluminum with steel cross-beams, were used to transport the cattle; all of which had two decks with a drop center (or possum belly) design, air suspension and five compartments; nose, deck, doghouse, belly and back (Figure 3.1). Seven of the 8 trailers were tri-axle (Merritt Equipment Co., Henderson, CO, USA; Wilson Trailer, Sioux City, IA, USA), and 1 was a quad-axle (Wilson Trailers, Sioux City, IA, USA).

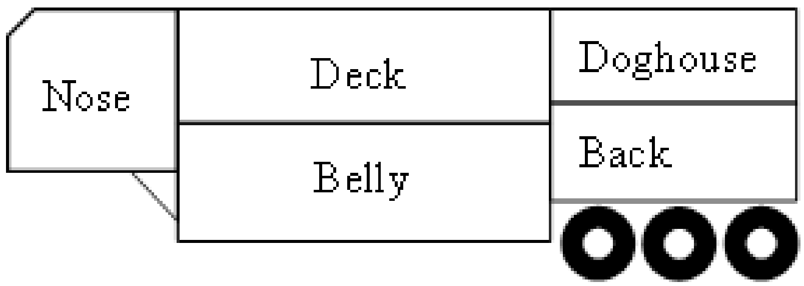

Figure 3.1 The layout of the five compartments within a potbelly tri-axle livestock semi-trailer.

Drivers were asked to fill out record sheets that included; the number of cattle in each compartment, the departure time and place, the arrival time and place, the condition of the cattle during the journey and reasons for any stops during the journey.

During loading the radio frequency identification (RFID) tags on each cow were scanned in loading order so that their compartment within the trailer could later be matched to carcass data received from the processing plant.

3.3.1 Accelerometers

At the time of data collection, the only commercially available, affordable product, which had an internal power source, was wireless and had a frequency of data collection at the required 200Hz was the X16-1C accelerometer. The X16-1C tri-axial accelerometers (Gulf Coast Data Concepts, Waveland, MS, USA) were used to measure the root mean square of acceleration (rms) within each compartment of the trailers. The accelerometers recorded acceleration in three orthogonal axes (x, y, z) at a sampling rate of 200 Hz for the entire journey or until the battery capacity of the accelerometer was too low to continue recording. The accelerometers were set at a sampling frequency of 200 Hz with a dead band setting of 0.718 m/s^2 and a dead band timeout of 60 seconds. A dead band setting was used to preserve the battery power when the accelerometers were experiencing acceleration levels at or below 0.718 m/s^2 in magnitude. The sampling rate used during this trial was 200 Hz which satisfied the Nyquist criterion, which states that the sampling frequency must be at least twice that of the highest frequency movement being classified (Robert et al. 2009). The normal frequencies of interest on a cattle trailer are well below 100 Hz and therefore the 200 Hz sampling frequency was considered sufficient (Personal communication 2013, Trever Crowe, University of Saskatchewan). A frequency weighting of 1 was used on the acceleration data; the reason for this weighting will be described in detail in the following discussion.

The axes correspond to the following directions on the cattle trailer; x (vertical), y (horizontal or front to rear) and z (lateral or side to side). Due to environmental conditions (below freezing temperatures) and the need for a wireless accelerometer with an internal power source the data collection duration was restricted. The X16-1C accelerometer using a single AA lithium battery in the environmental conditions within the study was unable to collect data for the entire journey length in all of the trailers. Therefore, data from the first 50% of the journey duration was used for data analysis. In two of the journeys the accelerometers were able to record 100% of the journey and a comparison of the first half to the full journey length was made for these two trips.

3.3.2 Accelerometer attachment

In order to rigidly attach the accelerometers to the trailer without damaging the trailer a 10-cm C-clamp was used. A bolt was passed through the body of the accelerometer and the arm of the clamp creating, rigidly attaching the accelerometer to the clamp. One clamp and accelerometer was then fastened to a cross-beam underneath the middle of each of the five compartments of the trailer (Figure 3.2). Two accelerometers were located inside the trailer (on the ceiling above the belly and back compartments) and three accelerometers were attached outside the trailer (under the nose, belly and back compartments). To protect the accelerometers from road debris (stones, mud etc.) and destruction by cattle, the accelerometers were wrapped in a 15-cm long foam tube. The C-clamps were tightly attached to the beams 10 cm from the passenger sidewall of the trailer. This method of attachment ensured a rigid connection between trailer and accelerometer, an efficient way of installing and removing the devices, would cause no damage to the trailer, provided protection from environmental damage, and would not pose a risk of injury to the cattle.

Figure 3.2 The accelerometer attachment method in a livestock semi-trailer using a C-clamp.

3.3.3 Accelerometer calibration

The 32 triaxial X16-1C accelerometers used for this research were calibrated in a laboratory setting by comparing their output with the output of a uniaxial piezoelectric accelerometer model 352C65 (PCB Piezotronics, NewYork, USA). All 33 accelerometers were rigidly attached to a hollow structural section, which was then bolted to a shaker-table, as described by Doranga et al. (2014). The shaker-table performed a frequency sweep from 1-20 Hz in 255 sec. A 1-20 Hz range was chosen because it represents the typical frequency range experienced by cattle on a livestock transporter (Gebresenbet et al. 2011). The orientation of the hollow structural section was changed twice so that the acceleration could be collected in all three axes (x, y, z). The X16-1C accelerometers were set at a sampling frequency of 200 Hz with a dead band setting of 0.718 m/s^2 and a dead band timeout of 60 seconds to match the settings used during actual data collection from the trailer. The 352C65 accelerometer was set at a sampling frequency of 400 Hz and the data were directly uploaded to a computer using the software by Vibpoint Framework by Data Solutions. The mean rms was calculated for each 15 s of data collected during the test creating 17 values used for comparison in each axes. The log of the rms values was used in the calibration to account for unequal variances across the range of accelerometer readings.

Linear regressions were performed to compare the output from the two types of accelerometers by determining the intercept and slope of the regression line. A general linear model (GLM) was used to determine if the slopes and intercepts varied between accelerometers.

3.3.4 Testing rigidity of accelerometer attachment

At the conclusion of the journey, it was noted that some c-clamps were moveable by hand but still clamped to the beam. It was necessary to test whether the data from these accelerometers was valid or whether it should be removed from the analysis. This was achieved by performing a fast fourier transform (FFT) on 20 sec of acceleration data from three suspected loose and three securely attached clamps using Matlab R14 SP2 (MathWorks, Natick, MA, USA). The resulting frequency spectrums were then interpreted and compared. Data from three loose accelerometers were then removed from analysis based on the visual recognition of peaks of acceleration at high frequencies (80-90 Hz), which were inconsistent with the secure sensors.

3.3.5 Global Positioning System

A Global Positioning System (GPS; Q Starz BT1000 Platinum, Qstarz International Co., Ltd, Ming Chuan, Taiwan) was placed in the tractor of each trailer to record the latitude, longitude and ground speed at a sampling frequency of one sample per minute. The GPS units and accelerometers had their internal clocks synchronized with one computer on Mountain Standard Time.

3.3.6 Carcass data collection

The animals from each of the research trailers were followed through the processing plant until they reached the area within the plant located after de-hiding and prior to carcass trimming. From that vantage point 2 observers assessed the bruising on the carcasses in 6 regions (figure 3.2). Bruising scores were given according to the size of each bruise using the three-point scale: 1) ≤ 6.5 cm; 2) 6.5 to 12 cm and 3) ≥ 12 cm (Hoffman et al. 1998). The bruising severity was determined by applying the weighted score to each of the bruises according to their size. Scores were added to result in one score for each carcass. The mean bruising severity was determined for each compartment by dividing the total bruise severity in the compartment by the number of carcasses scored within it. There were 8 trailers within the study but only 7 were used for bruise scoring because one of the trucks was delayed during the journey and the bruising data were unavailable.

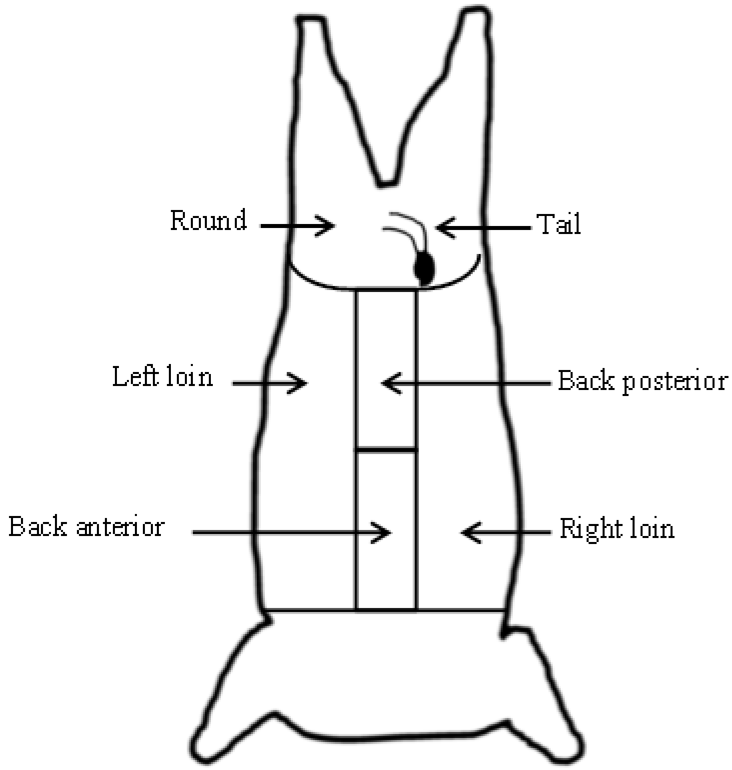

Figure 3.3 Bruising scores were assessed in six regions of the carcass; right loin (RL), left loin (LL), back anterior (BA), back posterior (BP), round (R) and tail (T).

An inter-observer score was determined for the bruising by location on carcass in the study by Goldhawk et al. (2014d). As the 291 carcasses scored for the current paper are a subset of the 589 scored during that trial, the inter-observer scores determined in that study will accurately represent the inter-observer score for the current study because the observers were the same throughout. The resulting Kappa between observers was 0.63 (P<0.01) and observers agreed on 99.5% of the bruise locations.

3.3.7 Statistical Analysis

SAS (v 9.2; SAS Institute Inc., Cary, NC, USA) was used to determine the descriptive statistics using the MEANS procedure and the regression equations for calibration using the REG procedure. The Mixed procedure in SAS 9.2 was used to determine the fixed effects of compartment on both acceleration (n=8) and bruising severity (n=7) using a completely randomized block design. Factors that were not significant were removed from the model by backwards stepwise elimination. A quadratic multiple regression in SAS was used to determine the relationship between acceleration and bruising severity with load as a random variable.

3.4 RESULTS

Calibration testing of the accelerometers resulted in high coefficients of determination (> 0.99) in all axes, indicating that the X16-1C accelerometers are good predictors of acceleration compared to the 352C65 “gold standard” accelerometer. There were, however, significant differences between the slopes and intercepts, suggesting that the X16-1C accelerometers should be calibrated using their own unique regression equations developed using the REG procedure in SAS 9.2. These regression equations were applied to all acceleration data prior to analysis.

Due to limitations in the battery capacity of the sensors, acceleration was only measured for the first half of the journey for all but two journeys. The percent difference in rms between the entire journey and the first half of those two journeys ranged from 7.22% to 14.54%.

Three data sets were removed from analysis based on results from the test for rigidity of attachment. When the FFT results were visually inspected, clear discrepancies were found between the sensors that were suspected to be loose and the securely attached sensors. When reviewing the frequency spectrums, amplitude peaks in the 80-90 Hz range indicated that their data were inconsistent with frequencies that could be expected to be found on a livestock semi-trailer therefore the data from these sensors were removed from the analysis. An example of the frequency spectrum from a suspected loose and securely attached sensor is given in Figure 3.4.

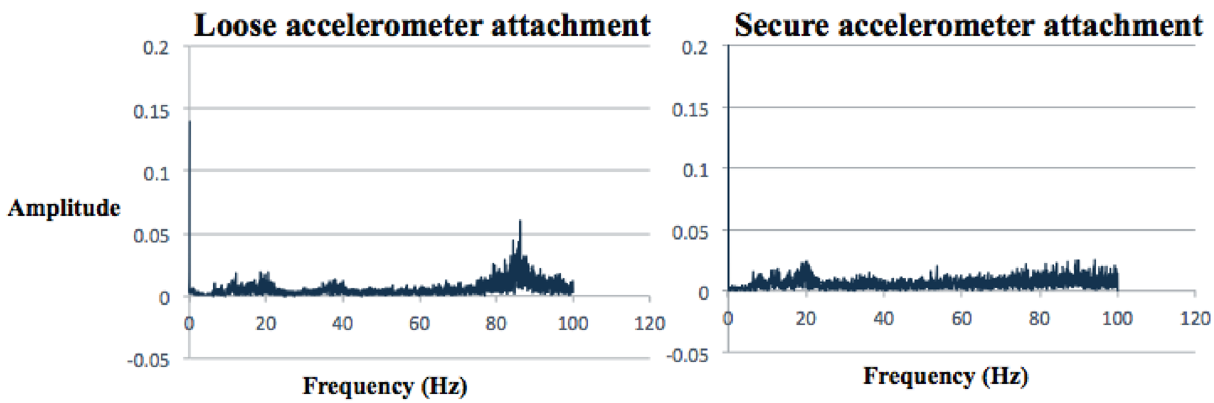

Figure 3.4 Frequency spectrums displaying the amplitude of acceleration at each frequency for a 20-second time period in the horizontal axis.

Descriptive statistics of the rms (m/s^2) from 31 accelerometers in five compartments are shown in Table 3.1. These values demonstrate the scope of the acceleration that cattle may be exposed to during a journey on a livestock semi-trailer. The vertical axis has the highest mean (1.01 ± 0.32 m/s^2), minimum (0.63 m/s^2) and maximum (1.90 m/s^2) rms values.

Table 3.1 Descriptive statistics of the rms of acceleration from 31 accelerometers attached to livestock semi-trailers transporting cull cows and the respective bruising number and severity per animal.

	n	Mean	SD	Min	Max
Vertical rms (m/s^2)	31	1.01	0.32	0.63	1.90
Horizontal rms (m/s^2)	31	0.72	0.31	0.33	1.81
Lateral rms (m/s^2)	31	0.97	0.30	0.49	1.51
Number of bruises per animal	40	4.52	2.43	0.38	12.75
Bruising severity per animal	40	5.31	2.85	0.38	14.88

The least squares means for bruising severity and acceleration in all three axes within each compartment of a trailer are represented in Table 3.2 and Figures 3.5 and 3.6. The doghouse tended to have higher bruising severity (7.58 ± 1.01) than the other compartments ($P \leq 0.11$). The lateral acceleration was greatest in the nose and back compartments ($P = 0.08$), whereas the horizontal acceleration was greatest in the nose, back and doghouse compartments (P = 0.05). The vertical acceleration had no significant relationship with compartment ($P = 0.86$).

Table 3.2 Least squares means (±SE) of bruising severity per animal on market cows and acceleration in five compartments of a livestock semi-trailer.

	Bruising severity[1]	Horizontal acceleration[2]	Lateral acceleration[3]	Vertical acceleration
Nose	5.80 ± 1.01^{ab}	0.94 ± 0.11^{a}	1.04 ± 0.11^{ab}	1.02 ± 0.12
Back	4.69 ± 1.01^{b}	0.82 ± 0.10^{a}	1.20 ± 0.10^{a}	0.95 ± 0.12
Doghouse	7.58 ± 1.01^{a}	0.82 ± 0.12^{a}	0.84 ± 0.12^{b}	1.01 ± 0.13
Deck	4.72 ± 1.01^{b}	0.53 ± 0.11^{b}	0.86 ± 0.11^{b}	0.94 ± 0.12
Belly	3.78 ± 1.01^{b}	0.53 ± 0.10^{b}	0.87 ± 0.10^{b}	1.09 ± 0.12

[1] Within a column means without a common superscript letter differ ($P = 0.11$).
[2] Within a column means without a common superscript letter differ ($P = 0.05$).
[3] Within a column means without a common superscript letter differ ($P = 0.08$).

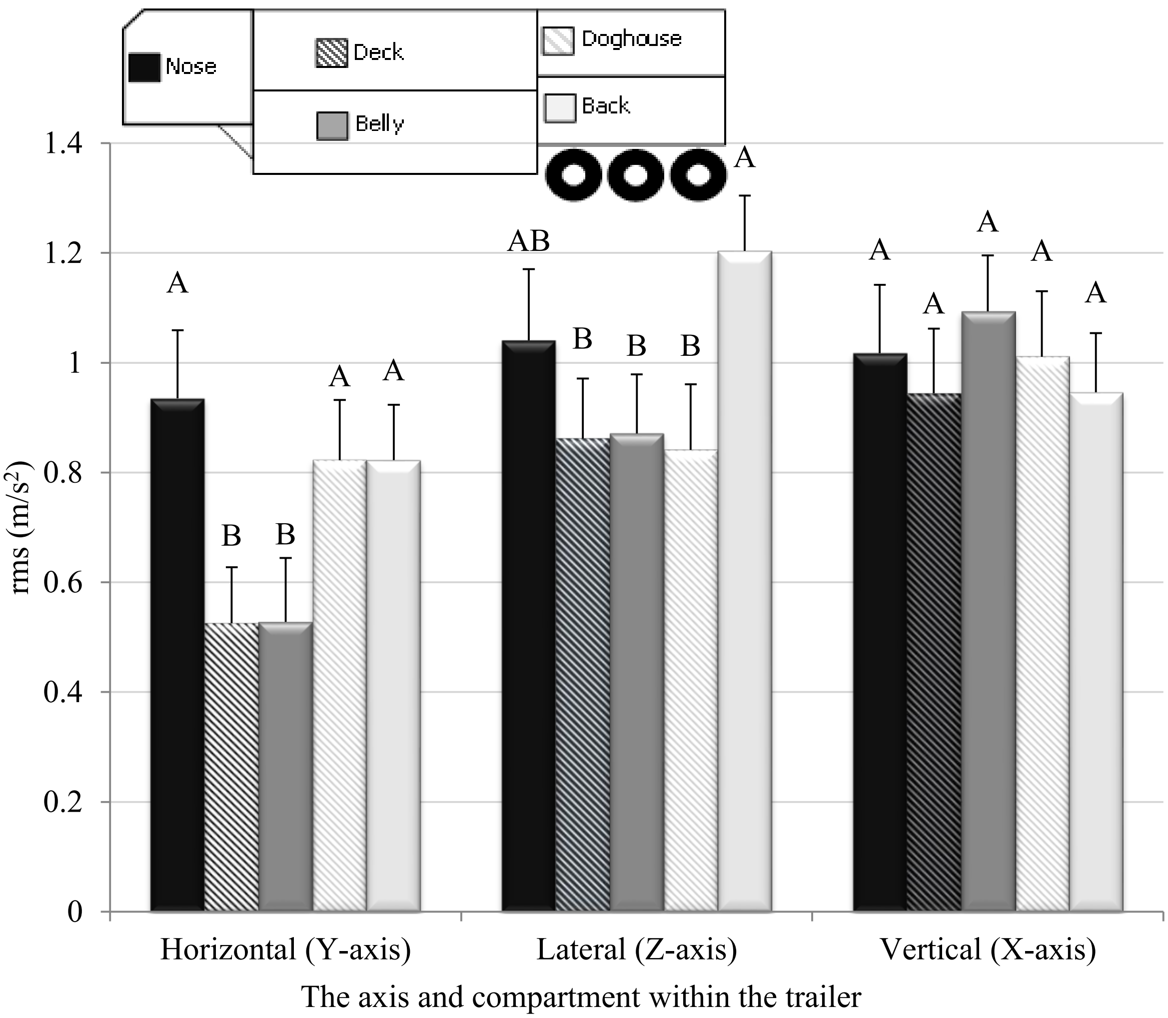

Figure 3.5 The least squares means (± SE) of the rms in all axes in each compartment of a livestock semi-trailer transporting cull cows.

ABC Bars with different superscripts differ by ($P < 0.1$)

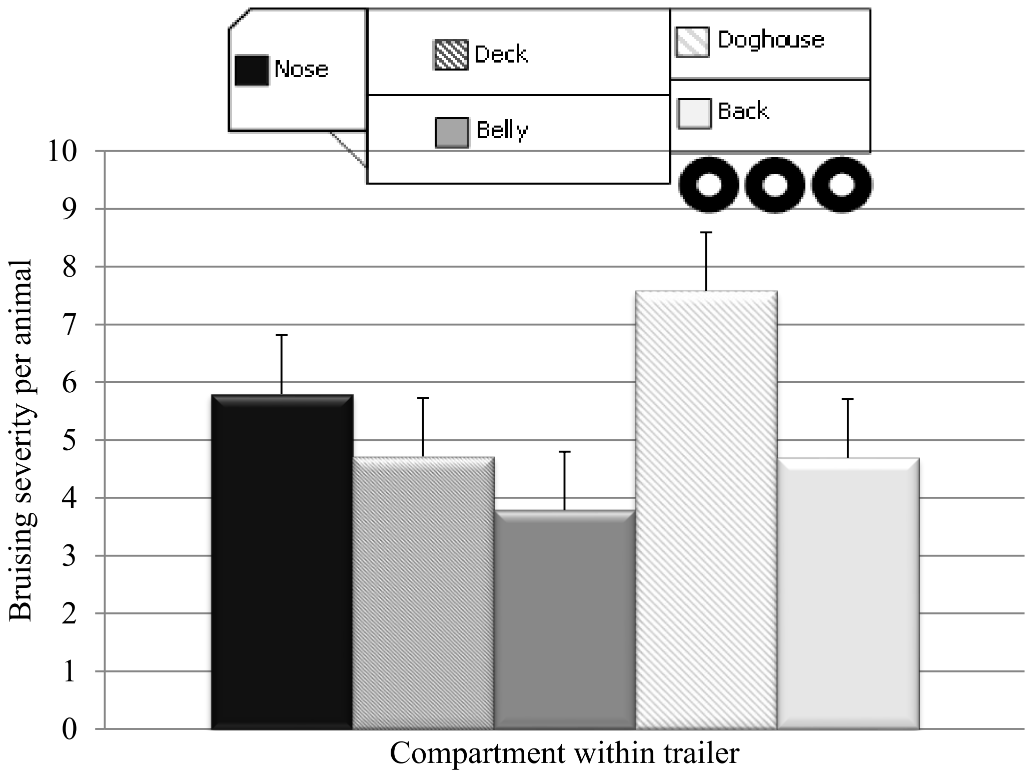

Figure 3.6 The least squares means (± SE) of the bruising severity per animal in each compartment of a livestock semi-trailer transporting cull cows ($P = 0.11$).

None of the axes of acceleration had a significant relationship with bruising; the greatest association was found in the lateral axis ($r^2 = 0.49$; P = 0.25) followed by the horizontal axis ($r^2 = 0.17$; P = 0.69) and vertical axis ($r^2 = 0.01$; P > 0.97). The number of replications in this study was small and there are a number of factors that can affect bruising which may have influenced the results. Further testing of this relationship is required before conclusions can be made.

3.5 DISCUSSION

In the present study, the mean rms values were 1.01 ± 0.32 m/s^2, 0.72 ± 0.31 m/s^2 , 0.97 ± 0.30 m/s^2, in the vertical, horizontal and lateral axes, respectively. These values are comparable to values reported by Gebresenbet et al. (2011), who measured acceleration on the frame of a European livestock trailer on three road types at four different speeds and had mean rms values of 1.52 ± 0.45 m/s^2, 1.32 ± 0.37 m/s^2, 0.81 ± 0.12 m/s^2 in the vertical, horizontal and lateral axis, respectively. Cann et al. (2004) reported a range of acceleration of 0.12 to 0.52 m/s^2 rms on highway transport truck drivers, which was lower than the accelerations measured on the trailer in the current study possibly because of the driver's seat mitigating accelerations. Another American study reported lateral accelerations of 0.69 to 2.74 m/s^2 when driving a loaded tractor-trailer through a slalom maneuver on gravel roads at speeds of 18.5 to 34.8 km (Clark et al. 1999). These values were likely higher than the current study because they travelled on gravel roads while continually turning, whereas, in the current study, the majority of travel was on straight, paved highways. In the current study all the rms measurements were below the level (2 m/s^2) above which humans report being extremely uncomfortable (Table 3.3) and below the level (3 m/s^2) above which pig welfare is considered compromised (Perremans et al. 1998). However, many of the rms values fell within the range that humans reported being very uncomfortable (Table 3.3).

Table 3.3 Likely human reactions to rms weighted acceleration levels[1]

rms weighted acceleration (m/s^2)[2]	Description
<0.315	Not uncomfortable
0.315-0.63	A little uncomfortable
0.5-1.0	Fairly uncomfortable
0.8-1.6	Uncomfortable
1.25-2.5	Very uncomfortable
>2.0	Extremely uncomfortable

[1] Randall (1992)
[2] Unweighted rms levels for animals (such as the ones in the current study) would be somewhat higher than these levels weighted for humans.

Acceleration includes motion such as shocks and jolts that could be experienced during rough braking or cornering as well as vibration. Vibrations have a magnitude (m/s^2) and a frequency (Hz) that affect the subject experiencing them. In humans, considerable research has been done on responses to vibrations of varying magnitudes and frequencies of vibration, which, at high levels, can cause muscular fatigue, reduced stability, discomfort and motion sickness (Cann et al. 2004). Most studies, even in livestock research, use frequency weighted rms values to account for changing sensitivity to vibration according to the general International Organization of Standardization (ISO) 2631-1 (1997) standards based on human degree of discomfort at a single vibration magnitude (Zhou et al. 2014). A recent study by Zhou et al. (2014) determined that frequency sensitivity changes at different magnitudes of vibration, indicating that the commonly used weighting scale should be updated. Not only does sensitivity change depending on the frequency-magnitude combination but also according to body size, body mass, age, gender and change of posture, also known as 'biodynamics' (Randall 1992; Zhou et al. 2014). Frequency weighting according to current standards could therefore inaccurately depict both human and cattle vibration sensitivity. It is especially hard to determine the frequencies at which livestock are most sensitive because of their inability to communicate their discomfort level. However, several studies have examined how physiological indicators change at different frequencies while other studies have measured resonance frequencies found on transported livestock and produce. It has been observed that higher magnitudes (> $3 m/s^2$) and specific frequencies (8 and 18 Hz) caused the highest stress, measured by heart rate, in pigs (Perremens et al. 1998). Resonant frequencies (a specific frequency at which the vibration oscillations increase in amplitude) have been established at 1.3, 5.1, 12.6 and 23 Hz in European cattle being transported in trailers (Gebresenbet et al. 2011). Greatest damage was caused to transported pears at 3.5 and 18.5 Hz and the pears were most susceptible to bruising below 40Hz (Slaughter et al. 1993). A frequency weighting of 1 was applied in the current study due to the lack of consistent information on cattle vibration sensitivity and the risk of unintentionally biasing the data with an inaccurate weighting scale.

The method developed, in the current paper, for utilizing the X16-1C accelerometer can now be applied to further commercial transport studies. It is recommended that individual accelerometer data be corrected using regression equations determined during calibration with an accelerometer which has the capacity to accurately capture sampling frequencies of 400 Hz or higher. New sensors have become available from Gulf Coast Concepts in late 2013 that have extended battery life and more protective cases, which could be valuable when using accelerometers in transport research. Enhanced battery life could remove the necessity of the dead band setting, making it simpler to apply frequency weighting to acceleration data, simpler to include frequency in the analysis and would result in increased strength of analysis (especially when an accurate frequency weighting scale is determined for cattle). The dead band setting could also be causing a slight but still perceptible over-estimation of the rms of acceleration. This is because the accelerometer, when given a dead band setting, does not record a data point when the change in motion is below a certain threshold. Although, in theory, this could happen at any acceleration rate, in reality most of the missing data points were around 0. This effect is quite small but could still influence the final rms values measured. Therefore, no data points would be missed if the dead band setting was not used.

The degree to which the trailer floor either attenuates or amplifies the acceleration experienced by the cattle was not measured in this study due to practical constraints. Supplementary research could include transmission measurements between frame, floor and cattle as was applied in the methodology of Gebresenbet et al. (2011) who reported transmission of acceleration from frame to floor of 55-73% and from floor to cattle of 100-158%. These findings suggest that acceleration experienced by the cattle could differ from those measured from the trailer frame because of attenuation of acceleration from frame to floor and amplification of acceleration from floor to cattle, depending on the axes.

This study used only the rms of acceleration to describe the accelerations that occurred within the trailers over the course of the journey. However, there are many other values that can be used to further describe accelerations such as: crest factor, vibration dose value, resonant frequencies and the power spectral density (Gebresenbet et al. 2011). The crest factor gives an indication of the peaks of acceleration that occur on a journey. Whereas the vibration dose value indicates the cumulative affect that the acceleration magnitude has over time. The vibration dose value is used in acceleration measurements for humans to determine the maximum allowable time that a person should experience a certain level of vibration. Further, the power spectral density indicates the amount of energy (combination of the frequency and magnitude of vibration over time) that the vibrations can transmit. The use of these values was restricted in the current study because of the methodology used to collect the accelerations. It is recommended that a dead band setting on the accelerometer be avoided so that the calibration can be determined on the raw acceleration values rather than the rms of acceleration. Other variables can then be calculated and an in-depth evaluation of the accelerations on livestock trailers and their effect on the livestock can be determined.

Changes in vibrations during transit can be caused by road conditions, the standing orientation of the cattle, vehicle suspension, trailer flooring and truck speed (Gebresenbet et al. 2011; Randall 1992). In the present study an association between horizontal (P=0.04) and lateral

(P=0.08) acceleration and compartment was observed. The highest accelerations in the lateral and horizontal axis were in the nose, back and doghouse compartments. Both the back and nose compartments are positioned directly over the tires of the trailer or tractor (Figure 3.1) and the nose compartment is in direct contact with oncoming wind from the tractor portion of the vehicle; these factors are possible explanations for the elevated vibrations in these compartments.

In the present study, no significant relationships between accelerations and bruising were found, however, further investigation into the association between the lateral axes and bruising may be warranted (r^2 = 0.49; P = 0.25). Although little, if any, research has been conducted to examine the relationship between accelerations and bruising, other transport factors can be used to corroborate the importance of accelerations, especially in the lateral and horizontal axes, and their impact on livestock welfare. Vertical accelerations are more dependent on the speed of the trailer than the other axes. The air suspension systems, found on the majority of semi-trailers, could attenuate vertical accelerations normally caused by road conditions (Grandin 2007; Gebresenbet et al. 2011). Vertical accelerations may still play a role in contributing to vibration and consequently muscular fatigue and motion sickness but may have a less substantial role in hindering cattle stability. In contrast, it has been reported that driving style (P<0.05) and cattle standing orientation (P<0.002) have a significant effect on the magnitude of lateral and horizontal accelerations experienced by transported livestock (Peeters et al. 2008; Gebresenbet et al. 2011). Peeters et al. (2008) also reported that lateral accelerations are an important stressor for pigs (measured by heart rate variability). Cattle standing orientation is most often perpendicular to the forward motion of the trailer because it helps them maintain balance and reduce the amount of lateral and horizontal accelerations they experience (Tarrant 1990; Gebresenbet et al. 2011). Maintaining balance during travel could help them avoid contact with other animals or the facilities and therefore reduce the incidence of bruising (Strappini et al. 2012). Driving style is defined by the overall speed, speed of turns and abruptness of starting and stopping (Peeters et al. 2008). The work by Tarrant (1990) and Strappini et al (2012) reported that the highest cases of loss of balance in cattle were during cornering and braking and that 3.8% of total bruising found on Chilean cows at slaughter was caused by cattle falling as a result of rough braking during transit. It follows that acceleration could be an influencing factor for the severity of bruising in cows because of its direct relation with driving style, which is already acknowledged as a risk factor for bruising in cattle and other welfare parameters in pigs.

Additional research exploring fixed levels of acceleration (high, medium and low), by controlling the animal type and stocking density, speed of the trailer, road conditions as well as the number and speed of turns is needed to more fully understand the impact of acceleration on bruising in transport cattle.

3.6 CONCLUSION

An important contribution of this research is the development of a methodology for utilizing commercially available accelerometers to measure motion in a livestock transport semi-trailer over long distances. These methods can now be applied to future commercial cattle research projects. Using this methodology, accelerations in commercial transport vehicles were found to range from 0.33 to 1.90 m/s^2, the mean vertical, horizontal and lateral axes acceleration were 1.01 ± 0.32 m/s^2 , 0.72 ± 0.31 m/s^2 , 0.97 ± 0.30 m/s^2, respectively. The nose, back and doghouse compartments had the highest rms values in both the lateral and horizontal axis. In contrast, the vertical acceleration did not differ by compartment. Although no significant relationship between acceleration and bruising was observed, the association between these two parameters warrants further investigation.

4. MANUSCRIPT II: Impact of transport variables on animal outcomes during commercial transport of finished cattle in Canadian winter conditions

4.1 ABSTRACT

Factors affecting the welfare and carcass quality of commercially transported finished cattle (n=1552) from feedlot to slaughter facility during western Canadian winter conditions. Transport, animal and handling variables were recorded, observed and scored prior to transport, during transport, post transport and after slaughter.

Extensive descriptive statistics for finished cattle transported in western Canadian winter conditions are listed. A significant three-way interaction between journey duration, ambient conditions and compartment was observed for ΔTemp, ΔHR and ΔTHI. A significant interaction between trailer compartment and waiting time resulted in an increase in ΔTemp, ΔHR and ΔTHI ($P < 0.0001$). Trailer acceleration in the vertical axis (x-axis) was significantly ($P = 0.03$) affected by the two-way interaction of journey duration and trailer speed. Horizontal (y-axis) and lateral (z-axis) trailer acceleration were significantly ($P < 0.0001$) affected by the two-way interaction of journey duration and compartment within the trailer. Horizontal (y-axis) acceleration was also significantly (P = 0.0005) affected by the two-way interaction of speed of trailer and compartment within trailer. Beta-agonist use, total wait time at the slaughter plant, vertical (x-axis) acceleration and the two-way interaction of bruise position on carcass and carcass yield were all significant factors in the final multivariable model predicting severe bruising. The final multiple regression model for shrink demonstrated a relationship ($r^2 = 0.856$; $P < 0.001$) between journey duration, maximum space allowance (allometric coefficient k), mean THI and prodding with shrink in finished cattle.

The results of this commercial study provide a detailed characterization of the effect of winter transport conditions on animal outcomes. Further, it will serve as a reference for other studies exploring those factors which significantly impact carcass outcomes in finished cattle transport.

4.2 INTRODUCTION

Both the welfare and productivity of finished cattle are affected by transport to a slaughter facility (Warren et al. 2010a; González et al. 2012c). Both of these parameters have practical and social implications for cattle producers, transporters, consumers and the public. Transport can affect the carcass quality of the cattle in terms of bruising (Romero et al. 2013), shrink (González et al. 2012a) and grading (Warren et al. 2010b), causing significant economic losses to the industry (NBQA 2013) and poorer quality products available to market. Transport can also affect the condition of the cattle from pre- to post-transport in terms of cleanliness, stress, lameness, injury and death (Tarrant 1990; Malena et al. 2006). Although finished cattle are the most robust cattle type transported (Schwartzkopf-Genswein et al. 2012) and are usually less detrimentally affected by transport, there are still opportunities for improving animal welfare and carcass outcomes through improved transport conditions.

The microclimate and motion experienced by finished cattle in Canadian winter conditions on North American cattle transport trailers have not been extensively studied. Therefore little is known about how to control or manipulate these factors in order to create the most suitable transport environment for finished cattle. The goal of the current study was to identify those factors related to trailer microclimate and motion which most significantly impact animal outcomes The results of the current study were designed to complement recent research on cull cows, feeder cattle and calves conducted by Goldhawk et al. (2014b:c:d)

The objectives of this study were to (1) benchmark transport variables including internal trailer microclimate, trailer acceleration, journey times, handling parameters and animal outcomes throughout the commercial transport of finished cattle in Canadian winter conditions and (2) to determine transport variables that affect the acceleration and internal trailer microclimate (3) and to determine the relationship between indicators of animal welfare (bruising and shrink) and transport variables.

4.3 MATERIALS AND METHODS

Data collection within this study was approved by the Animal Care and Use Committee of the Lethbridge Research Centre according to the guidelines established by the Canadian Council on Animal Care. The research staff did not control direct handling and care of the animals in this study.

Data for this trial were collected from November 28, 2013 until February 28, 2014. Journeys were separated into two main durations, >300 km was considered a long journey and <300 km was considered a short journey. The 300 km threshold was chosen based on research conducted by Hoffman et al. (1998) and Malena et al. (2006) which demonstrated an increased risk of bruising and mortality when cattle are transported more than 300 km. Whereas, Thrower (2009) used 500 km and González et al. (2012b) used 400 km as the criteria for being either a short or long journey. A detailed description of each part of the journey is provided in Table 4.1.

Table 4.1 Parameters describing each activity, from loading to slaughter of finished cattle transported from feedlot to slaughter facility.

Segment of Journey	Start description	End description
Loading	First animal enters the trailer	Last animal enters the trailer and the rear sliding door is closed
Journey	End of loading	Beginning of waiting
Waiting	Arrival at the slaughter facility	Beginning of unloading
Unloading	Rear sliding door is opened	Last animal exits the trailer
Lairage	End of unloading	First animal enters the stunning box within the slaughter plant
Total wait time	Arrival at the slaughter facility	First animal enters the stunning box within the slaughter plant

During some of the long-distance journeys, there were prolonged stationary periods, which did not occur on the short distance journeys. Two loads stopped for 11-12 min (reason unknown), two loads stopped for 21-22 min (reason unknown), two loads stopped for 50-51 min for lunch and four loads were delayed for 26 min on the highway due to congested traffic caused by construction. The delayed trucks were either stationary or travelling below 10 km/ h for the 26-min period. This does not include the time when loaded trailers stopped to wait for other trailers to finish loading at the beginning of the journey so that they could drive to their destination in a group.

4.3.1 Cattle management

The cattle in this study were all commercial finished cattle, under thirty months of age, of mixed breed (n=1345) or Angus (n=207). Heifers and steers were never mixed together within a single compartment of the trailer, however, on some loads they were transported within the same trailer. Cattle did not have access to feed or water during transport but did have access to water during lairage, however no observations were made during this time. Information regarding beta-agonist use at the feedlot was collected from the feedlot operator after loading the cattle.

The pen of origin at the feedlot was scored on the day of loading for the ground conditions. The pen condition on the days preceding transport was not recorded and may have affected cattle cleanliness at the time of loading (Table 4.4).

4.3.2 Animal condition

Cattle were visually evaluated for BCS cleanliness, injuries, lameness and serious health issues pre and post transport. These factors were scored individually prior to loading in a holding pen or as they were being walked through an alley and after unloading in a holding pen at the slaughter facility. Lameness examination was adapted from the method described by Desrochers et al. (2001), where a lame animal was defined as one with a gait score of 2 or greater (moderate and consistent gait asymmetry or symmetric gait abnormality). The Canadian 9-point scale was used to evaluate BCS just prior to cattle loading (AAFRD 2006). Only visual assessment for BCS was completed because of an inability to come into physical contact with individual animals.

The American Meat Institute's Guidelines and Audit Guide (2012) refer to animals that are non-ambulatory, injured (broken legs, swollen or injured eyes, visible cuts), or fatigued (open mouth panting, reluctance to move) as indication that the animal is compromised. These scores are described in Table 4.2. Each animal was also scored for a wet coat (fur appears soaked on sides or along the back of an animal) or for dirtiness. An animal was considered dirty if it had tag or mud above a curved line that extended from the tail head, along each side of the animal to the upper area of the front leg, as indicated in Figure 4.1.

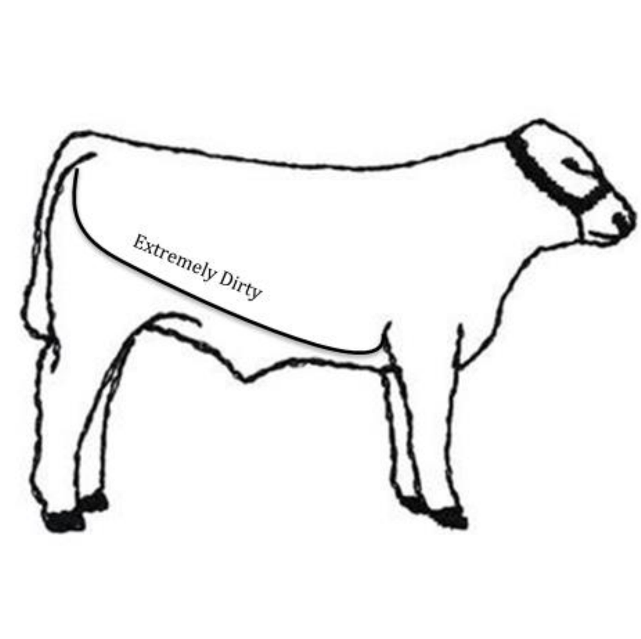

Figure 4.1 Line depicting the level of dirt above which the animal was considered extremely dirty.

4.3.3 Loading and unloading scores pre- and post-transport

Each animal's behaviour and the duration of (un)loading was scored on the (un)loading ramp by one person standing at a suitable vantage point, consistent with the methods developed by María et al. (2011). Animal handling and the speed cattle entered or exited the trailer were scored on a load basis according to the methods discussed in Warren et al. (2010a). Core Criteria 4 and 5 from the American Meat Institute's Guidelines & Audit Guide (2012) were also used to record the electric prod use and falls during (un)loading. All of these factors were included in the development of the criteria for scoring (un)loading and are described in Table 4.2.

Table 4.2 Description of the criteria used to develop the (un)loading and animal condition scores

Scoring method	Score	Score description	Factors involved	Description of factors
AMI criteria 4[1]	Excellent (E)	No falling	Falling	Part of the body other than limb touches the ground
	Acceptable (A)	<1%		
	Not acceptable (N)	1-5%		
	Serious problem (S)	>5%		
AMI criteria 5[1]	Excellent (E)	<5%	Prodding	Electric prod used during (un)loading
	Acceptable (A)	5-25%		
	Not acceptable (N)	25-50%		
	Serious problem (S)	>50%		
AMI criteria 6[1]	Excellent (E)	<1%	Compromised	Non-ambulatory – unable to walk or move
	Acceptable (A)	1-2%		Severe injury (broken legs, visible cuts, eye injury)
	Not acceptable (N)	2-3%		Fatigue (panting or reluctant to move)
	Serious problem (S)	>3%		
Handling score[1]	3	Most desirable	Handling	Shouting or banging on the trailer
Warren et al.	2	Less desirable		Use of side-rail when (un)loading
(2010a)	1	Least desirable		Animals hit back on rear sliding door
				Driving aid used to hit animals more than 5 times or electric prod use
Cattle speed [2]	1	Walk	Speed	Average speed cattle (un)loaded per compartment
Warren et al.	2	Trot		
(2010a)	3	Run		
Animal score [2]	1T[3]	Most desirable	Animal activity	Slip - temporary loss of balance that interferes with normal walking
María et al.	2T	Less desirable		Trip - temporary loss of balance; part of the leg touches the ground
(2004)	3T	Less desirable		Fall - loss of balance where chest or main body touches the ground
	4T	Less desirable		Mount - animal mounts another animal
	5T	Less desirable		Aggression - animal displays head butting, or threatening posture toward another animal
	6T	Least desirable		Balk - animal stops for more than 10 seconds
				Animal prodded

[1] The score was determined based on data from an entire load.
[2] The score was determined based on data from a compartment within a load.
[3] María et al. (2004) combined a time score, represented by letters, and the numbered score. In this trial cattle were all loaded within the fastest time score and therefore, only the T score is shown.

4.3.4 Transport vehicles

All of the 36 tractor-trailer units within the current study were of the Class 8 type with two decks and a drop center (or possum belly), air suspension and were constructed of aluminum with steel cross beams. No boarding was used to cover ventilation holes on the sides of any of the trailers used in the current study. All the trailers, with two exceptions, had five compartments; nose, deck, doghouse, belly and back (Figure 4.2). The trailers were all manufactured by Wilson Trailers (Wilson Trailers, Sioux City, IA, USA) or Merritt Equipment Co. (Merritt Equipment Co., Henderson).

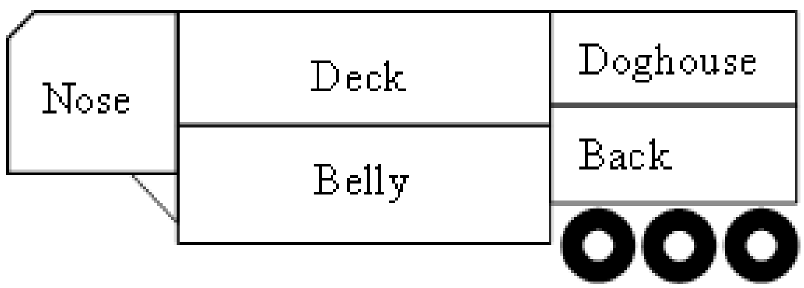

Figure 4.2 The layout of the five compartments within a potbelly tri-axle livestock semi-trailer.

Trailer floor area was calculated based on the dimensions of a subset of the trailers. These measurements were relatively consistent and thus applied to all the trailers. The doghouse compartment had 2 commonly used orientations for floor space; the L-shape or half-dog, which were calculated at either 75 or 50% of the back floor space, respectively, as in the study by Warren et a al. (2010a). The nose compartment is in the shape of an irregular hexagon and thus 0.181m^2 was removed from the total nose area to account for its shape.

The manure depth within each trailer was scored once prior to the journey and once after unloading, prior to trailer clean-out. The trailer was classified as either clean, or having frozen, dry or liquid manure and the height of the manure from the bottom of the trailer was measured. Bedding was not used on any of the journeys in the current study.

4.3.5 Space allowance

The space allowance (SA), percentage difference between recommended and observed space allowance (DRSA) and allometric coefficient (k) were determined using the following equations (González et al. 2012d; Petherick and Phillips 2009):

Equation 4.1 Observed SA (m^2/animal) = Area compartment / No. animals
Equation 4.2 Recommended SA (m^2/animal) = 0.01229 × body wt $^{0.7403}$
Equation 4.3 DRSA (%) = (Observed SA – Recommended SA)/ Recommended SA × 100
Equation 4.4 k = Observed SA/(body wt $^{0.6667}$)

4.3.6 Global positioning system

A Global Positioning System (GPS; Q Starz BT1000 Platinum, Qstarz International Co., Ltd, Ming Chuan, Taiwan) was placed in the tractor of each trailer to record the latitude, longitude and ground speed at a sampling frequency of 1 sample per minute. The GPS units, temperature sensors and accelerometers had their internal clocks synchronized with one computer on Mountain Standard Time.

4.3.7 Driver records

Drivers were asked to complete record sheets that included: the number of cattle in each compartment, the departure time and place, the arrival time and place, the condition of the cattle during the journey and reasons for any stops during the journey. These records were used to corroborate events recorded by the GPS units and the number of cattle in each compartment.

4.3.8 Radio frequency identification

During unloading of the cattle the radio frequency identification (RFID) tags were scanned as the cattle exited the trailer at the slaughter facility. The cattle exit the trailer in quick succession therefore it was not possible to read the tag of every animal. There were 973 out of 997 read tags that were able to be matched with carcass data from individual animals to their location within the trailer.

4.3.9 Inter-observer training

Inter-observer training was done between observers measuring (un)loading scores, BCS, and bruising. The unloading training consisted of two observers scoring five loads of cattle (n=212) on one occasion. The unloading of all trailers at the slaughter facility, during the actual data collection period, was observed by the same single person throughout. The loading training consisted of three observers scoring a total of 15 loads of cattle (n=676) in total over three different occasions. During the data collection period, the same single observer did the scoring of all the loads except on one occasion a different trained observer scored. The BCS training consisted of three observers scoring a total of 290 cattle over three occasions. A single observer did the scoring of BCS but this observer was changed mid way through the data collection period. Bruise score training consisted of three observers scoring a total of 208 carcasses over two occasions. Two observers scored the carcass bruising during the data collection period, on one occasion the second observer was changed; otherwise the observers remained the same throughout. Pearson correlations, percent agreement and Kappa equations were used, when applicable, to determine the reliability between observers (Hunt 1986).

4.3.10 Accelerometers

The X16-1C tri-axial accelerometers (Gulf Coast Data Concepts, Waveland, MS, USA) were used to measure the acceleration (g) within each compartment of the trailers. The acceleration was later converted to m/s^2, the force of gravity in the vertical direction was removed and the root mean square (rms) of acceleration was determined. The accelerometers recorded acceleration in three orthogonal directions; x (vertical), y (horizontal or front to rear) and z (lateral or side to side). The X16-1C accelerometers were set at a sampling frequency of 200 Hz with a dead band setting of 0.718 m/s^2 and a dead band timeout of 60 seconds. A dead band setting was used to preserve the battery power when the accelerometers were experiencing acceleration changes below 0.718 m/s^2 in magnitude. The accelerometers were attached to the trailer and calibrated according to the methods described in Manuscript I of this thesis using individual regression equations to correct for differences between the sensors and the standard.

4.3.11 Temperature sensors

The trailers were outfitted with sensors to measure temperature and humidity (HOBO U-23-001, Onset Computer Corporation, Bourne, MA, USA). Two sensors were placed on the outside of the trailer to measure ambient conditions, with sensor portion of the equipment enclosed in a perforated, opaque cover to protect from environmental damage during data collection. These sensors were positioned with the sensor component facing the back of the trailer on a specific rung of the first ladder on each side of the trailer. This location was chosen because it avoided the potential for warm air to reach the sensor from inside the trailer and was outside the range of area in which debris from the tires could reach. There were 7, 8, 3, 3 and 3, sensors attached to the ceiling of the belly, deck, back, dog and nose compartments, respectively (unless there was no doghouse compartment). The sensors were attached to the roof of each trailer along a beam either with zip-ties or with duct tape covering the body of the sensor with the sensor component always left uncovered. The location of the sensors on the ceiling, rather than at animal level, was validated as a suitable alternative location by Goldhawk et al. (2013). All the sensors were set to record the time, temperature and relative humidity at a sampling frequency of 1 sample per minute. A method of suspending the sensors in the nose compartment with ratchet straps, at a corresponding height to the other compartments, was developed after the beginning of the trial so only 25 of the 36 loads had sensors in the nose compartment. Sensors in the nose were placed at a height of >1.70 m and <1.83 m from the floor. Temperature and humidity sensors were calibrated prior to use in the study as described by Goldhawk et al. (2014d). Prior to analysis, all the microclimate data were visually inspected and removed if an irregular pattern was found compared to other sensors in the same compartment of a trailer.

4.3.12 Shrink

Equation 4.5 was used to determine the average body weight loss or shrink per animal (González et al. 2012a). Cattle weights were collected from the truck scales at the feedlot and from a group scale at the slaughter plant, which means that these are average weights for the trailer load of cattle.

Equation 4.5 Shrink (%) = [1 – (scale wt after transport / scale wt before transport)] × 100

4.3.13 Carcass data collection

After the animals were slaughtered there were two observers stationed at a vantage point prior to trimming and after de-hiding to score bruising on the carcasses. There were six regions on the carcass (Figure 4.3) that were scored according to the amount of bruising and the size of each bruise using a three-point scale: 1) ≤ 6.5 cm; 2) 6.5 to 12 cm and 3) ≥ 12 cm (Hoffman et al. 1998). The carcass positions defined in this study were back anterior (BA), back posterior (BP), left loin (LL), right loin (RL), round (R), and tail (T). A carcass was described by the total number of bruises as well as the total bruising severity, which is the addition of the bruises together after being weighted by size as either 1, 2 or 3. When comparing bruising with other transport factors, each carcass position was assessed as either having or not having a bruise of score 3 (the most severe score); thus creating a binary variable.

When determining the bruise score 3 on a position of a carcass the highest score from either observer was used. This method was used so that bruises of score 3 that were missed by one observer on a position would still be included in the data set, although it could have resulted in a slight overestimation of severe bruising in each position.

Carcass quality grade, kill order, yield grade, dark cutting and hot carcass weight data were collected from the slaughter plant records following the day of carcass observation. Cattle were all slaughtered on the same day as transport so that there was no overnight lairage. The quality grades in Canada are Prime (most desirable), AAA, AA, A and B4 (least desirable); the yield grades are Y1 (highest lean to fat ratio), Y2 and Y3 (lowest lean to fat ratio).

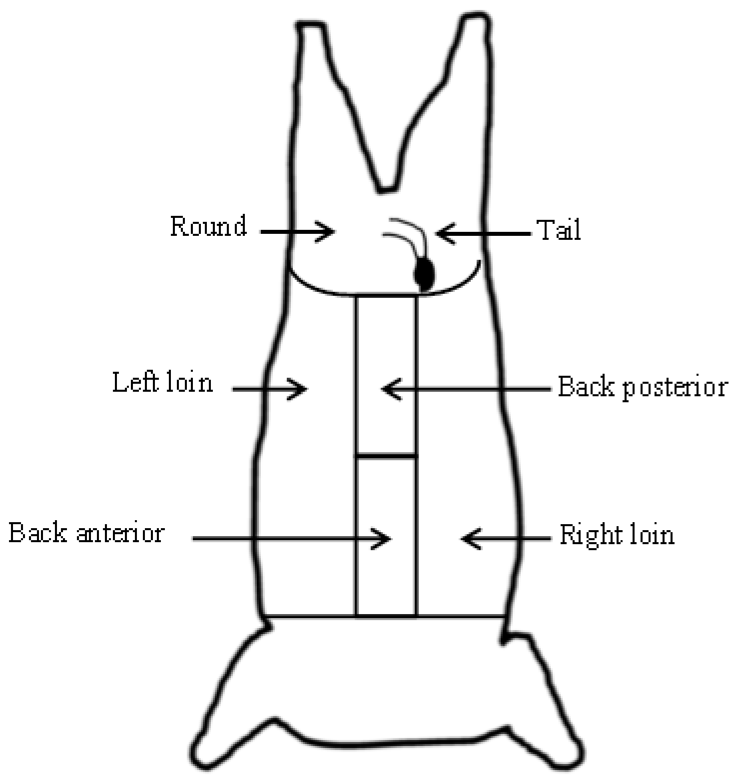

Figure 4.3 Bruising scores were assessed in six regions of the carcass; right loin, left loin, back anterior, back posterior, round and tail.

4.3.14 Statistical analysis

Statistical Analysis Software (v. 9.2, SAS Institute Inc., Cary, NC, USA) was used for all statistical analysis. The MEANS and FREQ procedures were used to determine descriptive statistics for continuous and categorical variables respectively. The UNIVARIATE procedure was used to test the distribution of each of the variables used in model analysis. General linear mixed models (GLIMMIX procedure in SAS 9.2) were used for determining the effect of transport variables on outcomes.

Space allowance was not used as an independent variable in any of the models because it was confounded with compartment. The range in space allowance was not the same between different compartments therefore not all treatments could be represented in each compartment and extrapolation errors could occur in the analysis if it were used.

Bruising severity was not used as a continuous dependent variable in any model because the distribution of the data was right skewed, even after a log transformation (log10) was applied.

Dark cutting was not used as a dependent variable in analysis because only eight carcasses (0.53%) were graded as B4 (dark cutting carcasses). AMI criteria 6 (compromised) was not used in the analysis because only one animal met the criteria. Changes in lameness and dirtiness of cattle between loading and unloading were not used in analysis because of the minimal change and the subjectivity of the scoring of the lameness in different loading conditions. Trucking company, feedlot and truck driver were not used as random effects because they were confounded with each other and with journey duration.

Microclimate model

The microclimate model was used to determine if temperature, humidity ratio (HR), or temperature humidity index (THI) were significantly affected by in-transit variables including, event during the journey, compartment and journey duration. The difference (Δ) between internal compartment microclimate and ambient conditions were used in analysis to account for different temperature ranges between loads. Time within the selected period was used as a repeated measure and ambient variables were used as covariates, similar to the methods used by Goldhawk et al. (2014d). The two journey events used for analysis were dynamic (the first 60 min of travel after loading) and steady state (the last 30 min of travel before arriving at the slaughter facility). The method of identifying the dynamic and steady state periods was similar to the method used by Brown et al. (2011) in which a visual inspection of the plotted data was used to characterize a pattern. A general linear mixed model (Glimmix procedure in SAS 9.2) was used for this analysis. This model was subjected to three variance-covariance structures: compound symmetry, autoregressive order and unstructured (Bryan 2013). The autoregressive covariance structure was the best fitting and was used for the repeated measures. Two and three-way interactions between variables were also tested.

The GLIMMIX procedure (SAS 9.2) was also used to determine the change in microclimate variables in each compartment while the trailer was stationary at the slaughter plant prior to unloading (waiting time). The compartment and elapsed time were applied as independent variables. A quadratic effect of elapsed time was also tested.

Acceleration model

The GLIMMIX procedure (SAS 9.2) was used to test the effect of trailer speed, journey duration, and compartment on the acceleration in all three axes of motion. Trailer load was used as a random variable and the Bonferroni method was used to adjust for multiple comparisons. Two- and three-way interactions between variables were tested.

Shrink model

The REG procedure (SAS 9.2) was used to test the regression of journey duration, maximum space per animal (k-value), the internal THI and electric prodding at loading with shrink in the final model. Shrink was measured on a per-load basis, therefore there were 32 loads with data measured. The other variables measured were also tested individually with shrink but only variables with a $P < 0.1$ were used in a multivariable model and only variables with a $P < 0.05$ remained in the final model. The quadratic effect of continuous variables was also tested individually. Continuous variables were tested for colinearity using the CORR procedure, VARCLUS procedure and the variance inflation factor (VIF) in the REG procedure of SAS 9.2; one variable from each cluster was chosen for final analysis with shrink in the multivariable model.

Variables tested individually with shrink were: journey duration, beta-agonist use, trailer motion (rms of acceleration in the x, y and z axes), (un)loading scores developed by Warren et al. (2010b), AMI criteria 5 (prodding), (un)loading prod score, k minimum, k maximum, k mean, DRSA minimum, DRSA maximum, DRSA mean, space allowance minimum, space allowance maximum, space allowance mean, THI minimum, THI maximum, THI mean, temperature minimum, temperature maximum, temperature mean, HR minimum, HR maximum, HR mean, lairage duration, loading duration, unloading duration, waiting duration.

Bruising model

The Glimmix procedure in SAS 9.2 was used to determine the effect of variables on the bruising in cattle. A binary score was developed, similar to that described in Goldhawk et al.

(2014d), in which a position on a carcass was given a score of 1 if the position had a bruise of size > 3 (by either observer), and a score of 0 was applied if the position had no bruises above size score 2. The model had a binary distribution and used the logit link function. The tail position of the carcass was removed from the analysis because only one tail had a score of 3. The random variables were carcass, compartment and load. Empty compartments were removed from the analysis.

A univariable analysis was used to test the effect of each individual variable on the bruise score 3. Variables with $P \leq 0.1$ were included in the multivariable model and were removed using a backwards stepwise elimination process until only variables with a significant effect on bruise score 3 remained ($P < 0.05$). Variables that were tested in the univariable analysis were: compartment, position on carcass, yield grade of carcass, waiting time, lairage time, (un) loading time, total wait time, beta-agonist use, sex of the cattle, journey duration, k-value (in categories), DRSA (in categories), space allowance, AMI criteria 4 (falling), AMI criteria 5 (prodding), max prod use at stunning area, (un)loading score developed by María et al. (2004), (un)loading scores developed by Warren et al (2010a), speed scores developed by Warren et al (2010a), as well as the mean, min and max rms of acceleration, internal temperature, internal HR and internal THI. The effect of the internal microclimate during the waiting period was also tested in the univariable analysis.

An odds ratio (OR) of less than 1 indicated that severe bruising is less likely to occur in a specific category than the reference category and a OR of greater than 1 indicates that severe bruising is more likely to occur in that category than the reference category.

The bruising analysis is based upon and combines aspects from similar analysis used in the studies completed by González et al (2012c) in Alberta and the USA, Warren et al (2010b) in Ontario, and Goldhawk et al (2014d) in Western Canada.

Significance were reported at $P \leq 0.05$ and trends were reported at $P \leq 0.1$.

4.4 RESULTS

4.4.1 Inter-observer training

Inter-observer reliability was tested for (un)loading scores, bruising scores and BCS during the training period. Observers of unloading had a correlation coefficient of r = 0.83 and a Kappa score of 0.77 during training. Observers of loading had an average correlation coefficient of r = 0.81 and an average Kappa score of 0.75 during training. Observers of BCS had an average correlation coefficient of r = 0.84 and an average Kappa score of 0.57 during training.

The inter-observer scores for bruising were based on the number of bruises, bruising severity and bruise score 3. Number of bruises and bruising severity were a score per carcass. Observers 1 and 2 had a correlation coefficient of r = 0.70 and observers 1 and 3 had a correlation coefficient of r = 0.82 for number of bruises they counted on each carcass. Observers 1 and 2 had a correlation coefficient of r = 0.81 and observers 1 and 3 had a correlation coefficient of r = 0.94 for their bruise severity scores on a whole carcass.

During the training period observers 1 and 2 had 97.10% agreement for bruise score 3 on a whole carcass with a Kappa of 0.55. Observers 1 and 3 had 96.00% agreement on the bruise score 3 on the whole carcass with a Kappa of 0.62. The data from the entire trial were used to compare inter-observer reliability between the two main observers (1 and 2) for bruise score 3 on individual positions on a carcass. The entire trial data were used because of the low number of severe bruises (of score 3) that were reported in the training period in some of the carcass positions. The resulting Kappa scores between observers 1 and 2 were 0.50, 0.45, 0.37, 0.61, 0.28 and 0.54 for all of the positions combined, BA, BP, LL, R and RL, respectively. The agreement between these observers for all the positions separately and combined ranged between 95.30% and 99.16%.

4.4.2 Descriptive statistics

Data were collected on 1552 cattle with 43.11 ± 2.48 (mean ± SD) animals per load in 36 loads within 16 weeks during western Canadian winter conditions. The BCS of those cattle were 4.11 ± 0.312 (mean ± SD) as described in Table 4.3. Cattle were at the feedlot between 129 and 420 days (Table 4.3) and during that time 74% were not sorted. The remaining 26% were sorted once or twice (Table 4.4). The majority of the cattle were fed on the morning of transport (n=1411), while the remaining cattle were fed the evening prior to transport (n=141) (Table 4.3). All pens were frozen on the day of transport with a score ranging from 0 to 2 (0=no snow, 1=<5cm of snow, 2=5-10cm of snow). Descriptive statistics of animals, carcasses, journey durations, trailers, drivers, space per animal, acceleration, microclimate and handling are presented in Tables 4.3, 4.4 and 4.5. Continuous variables are described by the mean, SD, max, min and n, whereas, categorical variables are described using the percent and n in each category. Variables that were measured pre and post transport are presented in Table 4.5, however, no statistical differences were calculated between the pre- and post-transport values in this table.

General trailer and driver information

A single driver did not drive more than four loads during the project. At least three loads of cattle were followed from each feedlot; all 15 long-distance journeys came from the same feedlot. Trailers had between 39 and 48 cattle loaded in at least four of the five compartments in the trailer (Table 4.3). Trailer speed was measured by GPS units located in the tractor cab and the portion of time spent at each speed category is listed in Table 4.4. During the journey (see Table 4.1 for description of journey) the trailers spent the most time travelling > 90 km/h, followed by 10 – 50 km/h, 50 – 90 km/h, < 1 km and 1-10 km/h. Sixty-four percent of trailer compartments were completely clean prior to loading and therefore had a manure height of 0 cm. The others had either frozen or liquid manure in them (Tables 4.3 and 4.4). The manure where present, reached a maximum height at the first punch-hole in the trailer wall, which was at approximately 8 cm above the floor of the trailer compartment (Table 4.3). At unloading 3% of the trailer compartments had 0 cm of manure, which means they did not have cattle in them (Table 4.3 and 4.4). At unloading, 70% of the trailer compartments had liquid manure in them and 28% had frozen manure (Table 4.4).

The trailers were of five different styles: Wilson fat wagon (n=1), Wilson quad (n=4), Merritt tri (n=22), Merritt quad (n=8), Merritt fat wagon (n=1). The Wilson fat wagon had no doghouse and a combined nose and deck compartment. The Merritt fat wagon had no doghouse but was like a regular tri-trailer otherwise. In some loads the doghouse was not loaded with cattle (n=11) and in some loads the nose was not loaded with cattle (n=2).

Compartment heights were 1.57 ± 0.02, 1.85 ± 0.03, 1.79 ± 0.01 and 1.49 ± 0.03 m in the back, belly, deck and doghouse, respectively. The full height of the nose compartment was 2.79 m, however in some of the trailers there was decking at a height of 1.81 ± 0.05 m (n=18).

Journey duration

The duration of journey segments are listed in Table 4.3. Short journeys (<300 km) did not take more than 4 h and long journeys (> 300 km) did not take more than 7 h 34 min. Loading took longer than unloading by an average of 3 min and neither took longer than 19 min in total. The longest time that a trailer waited at the slaughter plant before unloading was 1 h 24 min and the longest time a load of cattle waited in lairage before slaughter was 5 h 8 min.

Handling and (un)loading scores

The number of cattle in each category of the (un)loading score adopted from that of María et al. (2004) is shown in Table 4.5. This score consisted of a number to represent the cattle's behaviour during loading combined with a letter to represent how fast the cattle loaded, however all loads were within the same letter score. All cattle loaded at a rate faster than 1 min per animal and unloaded faster than 0.5 min per animal. Cattle were more likely to score better during unloading (scores ranged from 1 to 2) than during loading (scores ranged from 1 to 5) for the behavioural portion of the score. Only 20.13% had the best score during loading, whereas 84.34% had the best score during unloading indicating a difference in handling techniques between loading and unloading. Most cattle walked onto the trailer (92.17%) and trotted off the trailer (66.69%). It was more common for cattle to run off the trailer at unloading (9.21%) than for cattle to run onto the trailer during loading (0.54%) (Table 4.5). At loading, 33 loads scored ‘excellent’ for AMI criteria 4 (falling). There were 0.13 % of cattle that fell during loading, which caused three loads to move to the ‘not acceptable’ score (Table 4.5). During unloading more animals fell (0.52%) causing eight loads to be in the ‘not acceptable’ category. Prods were not used at unloading so all loads received an AMI criteria 5 score of ‘excellent’. During loading prods were used on 19.78% of the cattle, which left only 22.22% of loads in the ‘excellent’ category and moved the rest of the loads into the ‘acceptable’, ‘not acceptable’ or ‘severe problem’ categories (Table 4.5).

Cattle condition

Beta-agonists were used on approximately a quarter of the cattle (Table 4.4). The cattle in this study were a typical weight for finished cattle in Canada; there were 905 heifers weighing 635.74 ± 32.82 kg (mean ± SD) and 647 steers weighing 716.43 ± 25.66 kg (mean ± SD) (Table 4.3 and 4.4). There was a decrease (-4.15 %) in dirty animals, an increase (+3.22 %) in wet animals, an increase (+0.39 %) in dirty and wet animals and an increase (+1.46 %) in lame animals between loading and unloading, however the significance of these changes was not tested (Table 4.5). There was only one animal reported as compromised for AMI criteria 6 in all 36 loads so only 1 load received a score of less than ‘excellent’ (Table 4.5). The compromised animal showed signs of fatigue; drooped head, salivating and unwillingness to move.

Space allowance

The loading density is shown in Table 4.3 and 4.6 using the SA, k-value and DRSA values for each trailer compartment. It is important to note that the nose and doghouse compartments on average had 1.5 - 1.8 times higher mean SA and k-value than the other compartments. The doghouse and nose also had a positive DRSA value indicating that these compartments, on average, had more space for each animal. In fact, they were approximately 50% above the recommended space on average but reached a maximum of 138 to 144% above the recommended space allowance, whereas, the other compartments (deck, belly and back) were usually loaded at or below the recommended SA or to a maximum of 14% above the recommended level.

Table 4.3 Descriptive statistics of the variables associated with the transport of finished cattle from feedlot to slaughter during Canadian winter conditions.

Category	Variable	Mean	SD	Min	Max	n[1]
Animal and carcass	Days on feed at feedlot	190.31	90.61	129.00	420.00	167
	BCS (scale of 1-5)	4.11	0.29	3.00	5.00	1552
	Average heifer weight (kg)[2]	635.74	32.82	584.54	703.40	32
	Average steer weight (kg)[2]	716.43	25.66	641.29	757.73	32
	Shrink (% of body weight)[2]	2.14	0.10	0.25	3.88	32
	Number of bruises per animal	1.18	1.11	0.00	6.00	1552
	Bruising severity per animal[3]	1.84	1.97	0.00	12.00	1552
	Hot carcass weight (kg)	378.32	39.79	225.35	512.47	1519
Trailer and driver	Loads transported per driver	1.94	1.09	1.00	4.00	36
	Number of loads from each feedlot	6.00	4.56	3.00	15.00	36
	Number of animals in a trailer load	43.11	2.48	39.00	48.00	36
	Manure height pre-transport (cm)	0.71	1.30	0.00	7.62	36
	Manure height post-transport (cm)	3.05	1.83	0.00	7.62	6
	Time of day at loading (h:min)	08:52	1:36	06:30	12:11	36
Duration of journey segments[4]	Short journey duration (min)	182.19	38.22	101.00	240.00	21
	Long journey duration (min)	388.87	32.46	331.00	454.00	15
	Loading duration (min)	9.40	2.68	5.00	19.00	35
	Unloading duration (min)	5.92	1.63	4.00	10.00	36
	Waiting duration (min)	26.11	22.08	1.00	84.00	35
	Lairage duration (min)	117.33	66.43	40.00	308.00	36
	Total wait time (min)	141.63	64.03	64.00	309.00	35
Space per animal	SA (m^2/animal)	1.70	0.57	1.15	3.94	36
	k[5]	0.022	0.007	0.015	0.049	32
	DRSA (%)[6]	11.72	35.18	-26.08	144.48	32
Trailer acceleration	Vertical x-axis (m/s^2)	0.76	0.50	0.22	9.75	144
	Horizontal y-axis (m/s^2)	1.13	0.53	0.27	3.45	144
	Lateral z-axis (m/s^2)	0.92	0.69	0.16	6.33	144
Microclimate	Internal Temp (°C)	-5.80	2.79	-32.35	24.67	167
	Internal THI	-15.37	7.20	-54.20	26.25	167
	Internal HR (g water/kg dry air)	2.83	0.70	0.21	11.53	167
Prodding	Prodding in stunning area	0.03	0.31	0.00	7.00	34

[1] The n is based on the number of loads (36), compartments (180) or animals (1552). Missing data is due to equipment failure or unforeseen logistical complications.

[2] Animal weights and shrink were calculated using the average difference between pre and post-transport weight of all the cattle on a load.

[3] Bruising severity was calculated using the number of bruises weighted by their size.

[4] Descriptions of journey parameters can be found in Table 4.1.

[5] k = Observed SA/(body weight $^{0.6667}$)

[6] DRSA (%) = (Observed SA – Recommended SA)/ Recommended SA × 100

Table 4.4 The frequency at which each variable was realised during the transport of finished cattle during Canadian winter conditions.

Variable	Category	%	n
Prodded at stunning box	No	98.63	1436
	Yes	1.37	20
Sex of animal	Heifer	55.69	905
	Steer	44.31	647
Beta-agonist	Yes	25.75	439
	No	74.25	1113
Description of trailer floor pre-transport	Clean	64.02	105
	Frozen	18.29	30
	Liquid	17.68	29
Description of trailer floor post-transport	Clean	3.03	5
	Frozen	27.27	45
	Liquid	69.7	115
Feedlot pen score[1]	0	41.92	610
	1	28.14	428
	2	29.94	514
Number of times cattle were sorted at the feedlot	0	73.65	1079
	1	20.96	370
	2	5.39	103
Breed	Mixed Breed	88.02	1345
	Angus	11.98	207
Time of last feeding prior to transport [2]	12 < 24 h	10	141
	< 6 h	90	1411
Percent of journey time (min) spent at each speed[3]	< 1 km/h	6.82	597
	1-10 km/h	3.33	291
	10-50 km/h	19.56	1712
	50-90 km/h	15.79	1382
	> 90 km/h	54.5	4769
Grade	Prime	3.43	52
	AAA	70.53	1070
	AA	25.31	384
	A	0.2	3
	B4 (dark cutter)	0.53	8

[1] The pen score is based on the depth of mud, water or snow (0 = none, 1 = 1-5 cm, 2 = 5-10 cm).

[2] Water was available to all cattle until moved out of home pen in preparation for loading.

[3] Description of journey parameters available in Table 4.1.

Table 4.5 The frequency of loading and unloading scores in finished cattle transported during Canadian winter conditions.

		Loading		Unloading	
Scoring system[1]	Score	%	n[2]	%	n[2]
Animal score	1T (best)	20.13	32	84.34	140
María et al. (2004)	2T	45.91	73	15.66	26
	3T	22.64	36	0	0
	4T	6.29	10	0	0
	5T	5.03	8	0	0
	6T (worst)	0	0	0	0
Cattle speed	1 (walk)	92.17	1354	24.1	374
Warren et al. (2010a)	2 (trot)	7.28	107	66.69	1035
	3 (run)	0.54	8	9.21	143
Handling score	3 (best)	0	0	0	0
Warren et al. (2010a)	2	38.89	14	75	27
	1 (worst)	61.11	22	25	9
Condition	Good condition	67.1	991	66.11	1026
	Dirty	23.29	344	19.14	297
	Wet	9.28	137	12.5	194
	Dirty and wet	0	0	0.39	6
	Lame[3]	0.34	5	1.8	28
AMI criteria 4	No falling	99.87	1508	99.48	1544
	Fell	0.13	2	0.52	8
AMI criteria 4[4]	E	94.29	33	77.78	28
	A	0	0	0	0
	N	5.71	3	22.22	8
	S	0	0	0	0
AMI criteria 5	No Prodding	80.22	1245	100	1552
	Prodding	19.78	307	0	0
AMI criteria 5[4]	E	22.22	8	100	36
	A	33.33	12	0	0
	N	33.33	12	0	0
	S	11.11	4	0	0
AMI criteria 6	Uncompromised	100	1552	99.94	1551
	Compromised	0	0	0.064	1
AMI criteria 6[4]	E	100	36	97.22	35
	A	0	0	0	0
	N	0	0	2.78	1
	S	0	0	0	0

[1] Scoring methods are described in Table 4.2.

[2] Missing data was due to poor visibility during scoring or unforeseen logistical challenges.

[3] Lame refers to moderate and consistent gait asymmetry or symmetric gait abnormality, but still able to walk (Desrochers et al. 2001).

[4] E = excellent, A = Acceptable, N = Not acceptable, S = Serious problem

Table 4.6 Descriptive statistics for space allowance (SA), allometric coefficient (k)[1] and percentage difference between recommended and observed space allowance (DRSA)[2] in trailers transporting finished cattle.

Compartment	Variable	Mean	SD	Min	Max	n[3]
Nose	SA (m^2/animal)	2.21	0.60	1.51	3.94	34
	k	0.03	0.007	0.019	0.048	30
	DRSA (%)	49.22	34.93	-4.27	137.64	30
Deck	SA (m^2/animal)	1.39	0.08	1.23	1.55	36
	k	0.018	0.001	0.016	0.021	32
	DRSA (%)	-7.86	5.92	-19.98	5.69	32
Belly	SA (m^2/animal)	1.32	0.08	1.15	1.47	36
	k	0.017	0.001	0.015	0.019	32
	DRSA	-12.8	5.36	-26.08	-1.38	32
Doghouse	SA (m^2/animal)	2.37	0.62	1.55	3.94	25
	k	0.03	0.01	0.02	0.05	21
	DRSA (%)	49.86	38.24	3.19	144.48	21
Back	SA (m^2/animal)	1.46	0.16	1.24	1.80	36
	k	0.019	0.001	0.017	0.023	32
	DRSA (%)	-4.37	6.94	-16.66	14.19	32

[1] k = Observed SA/(body weight $^{0.6667}$)

[2] DRSA (%) = (Observed SA – Recommended SA)/ Recommended SA × 100

[3] Missing compartment data due to empty compartments or missing animal weights.

Microclimate

Described in Table 4.3 and Figures 4.4, 4.5 and 4.6 are the microclimate variables that were recorded internal and external (ambient) to the cattle trailers. The ambient temperatures were within the normal range of temperatures recorded during 1981-2010 in Alberta, Canada during October to February (Environment Canada 2015). Temperatures in this area during these months can range from 30 °C to -45 °C but are on average between 5 and -7 °C.

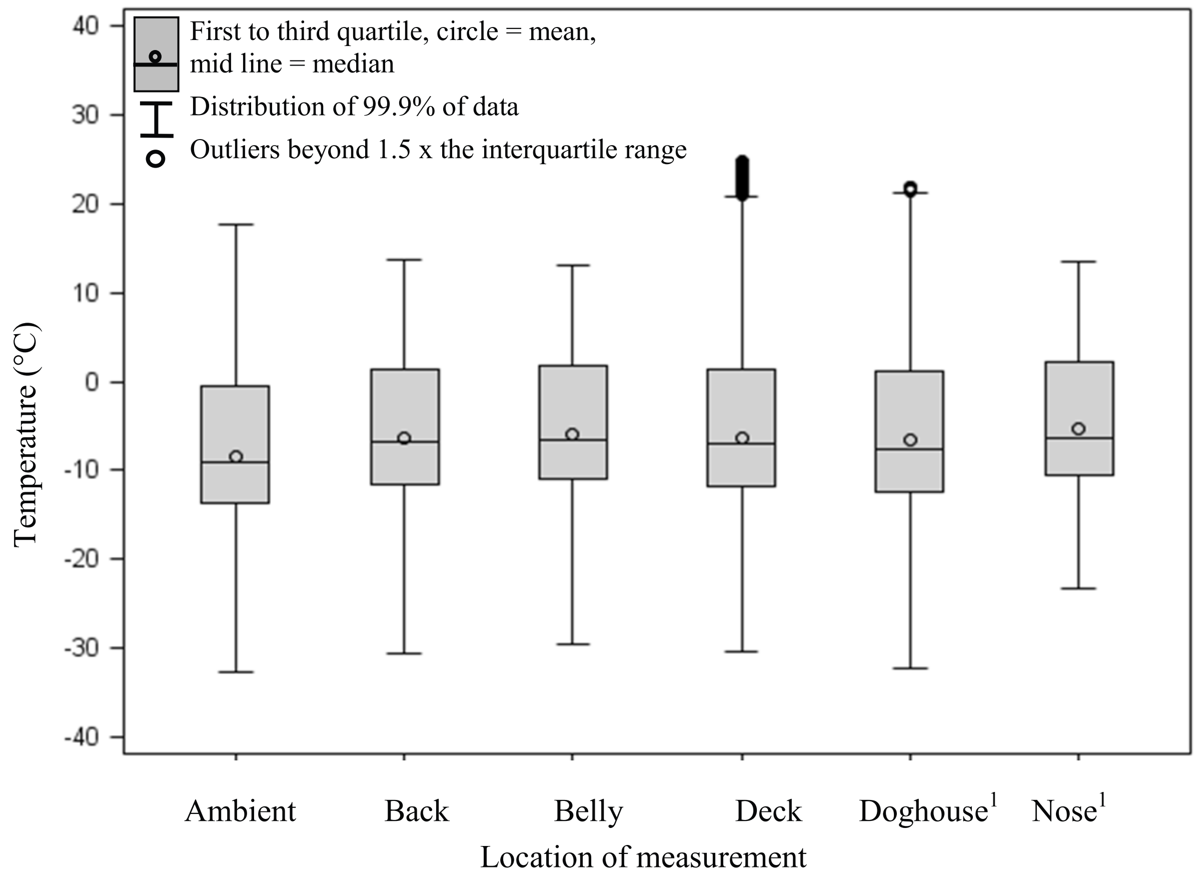

Figure 4.4 The distribution of the internal and ambient temperature in each compartment of 36 livestock semi-trailers during the transport of finished cattle from loading at the feedlot to unloading at the slaughter facility in Canadian winter conditions.

[1] Data from empty nose (n = 2) and doghouse (n = 11) compartments are included in these boxplots.

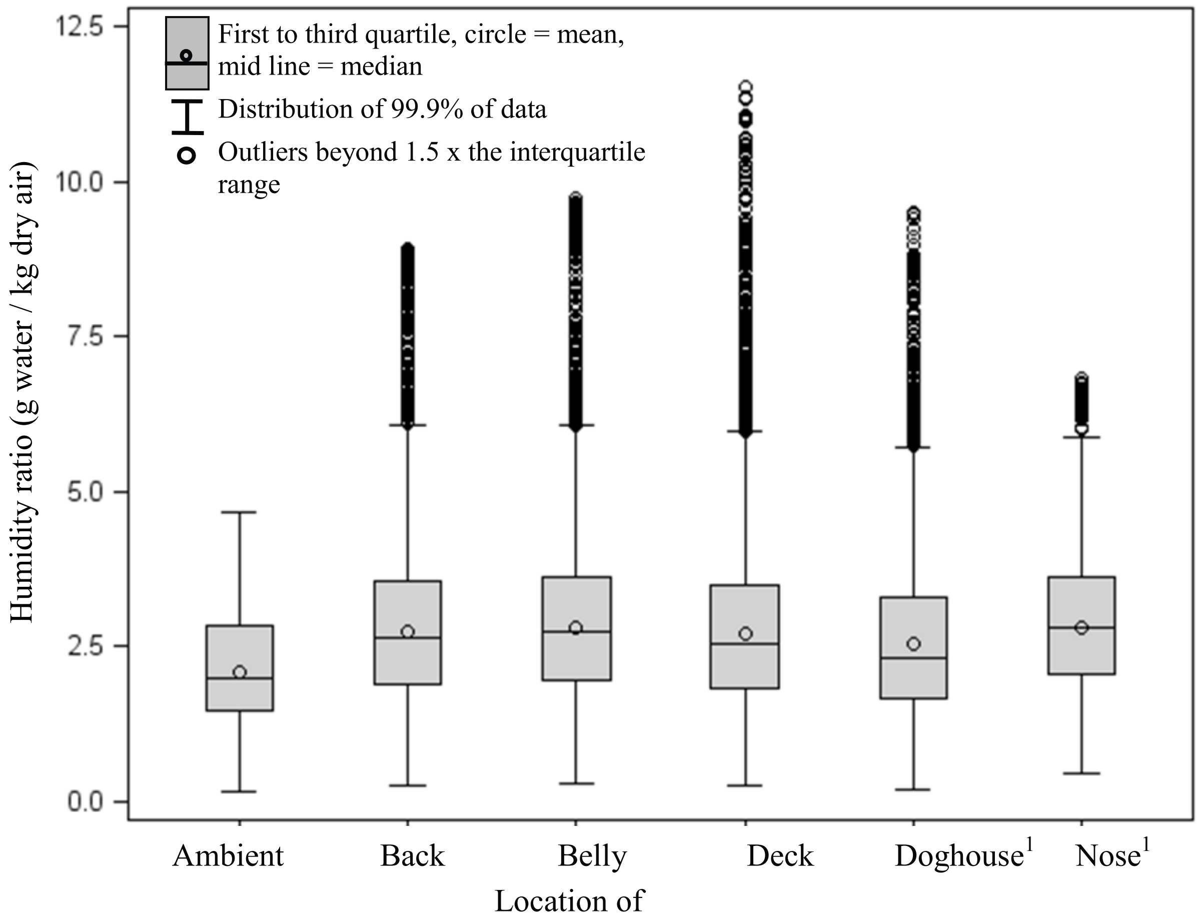

Figure 4.5 The distribution of the internal and ambient humidity ratio in each compartment of 36 livestock semi-trailers during the transport of finished cattle from loading at the feedlot to unloading at the slaughter facility in Canadian winter conditions.

[1] Data from empty nose (n = 2) and doghouse (n = 11) compartments are included in these boxplots.

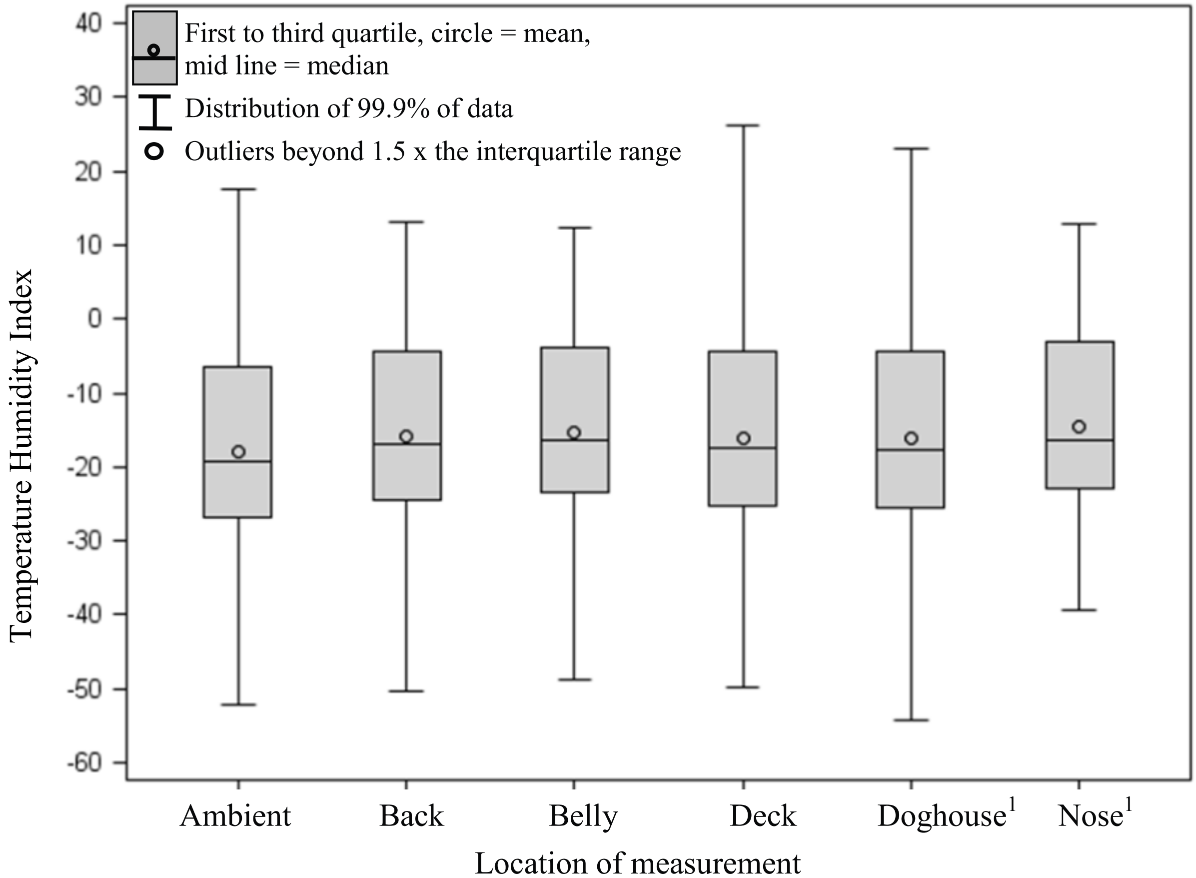

Figure 4.6 The distribution of the internal and ambient temperature humidity index in each compartment of 36 livestock semi-trailers during the transport of finished cattle from loading at the feedlot to unloading at the slaughter facility in Canadian winter conditions.

[1] Data from empty nose (n = 2) and doghouse (n = 11) compartments are included in these boxplots.

Acceleration

Descriptive acceleration data can be found in Table 4.3. The horizontal axis (y-axis) had the highest mean acceleration (1.13 ± 0.53 m/s^2) and the smallest range in acceleration (0.27 to 3.45 m/s^2). The vertical axis (x-axis) had the lowest mean acceleration (0.76 ± 0.5 m/s^2) and the largest range in acceleration (0.22 to 9.75 m/s^2). The lateral axis (z-axis) had a mean rms of acceleration (0.92 ± 0.69 m/s^2) and an rms of acceleration range of 0.16 to 6.33 m/s^2.

Shrink

Average shrink for all loads in this study was 2.14 ± 0.1% and ranged from 0.25% to 3.88% (Table 4.3).

Carcass Characteristics

The hot carcass weights for all cattle were 378.32 ± 39.79 kg (mean ± SD) (Table 4.3). Trained officials graded the carcasses according to the Canadian Beef Grading Agency standards. According to this grading system there were 3 (0.2%) A, 384 (25.3%) AA 1070 (70.53%) AAA, 52 (3.4%) Prime and 8 (0.53%) B4 grade (dark cutting) carcasses. No visible bruising was recorded on 75.51% of the total carcass area (Figure 4.7). The greatest number of bruises were size score 1 (13.40%) followed by size score 2 (6.00%) and size score 3 (5.09%). The bruises of the largest size and greatest severity (score 3) accounted for 20.78% of all the bruises scored. The T had the highest percentage of small sized bruises (score 1) followed by BP and R. Whereas, the RL and BA had the highest percentage of large sized bruises (score 3) and the tail had the least because it does not have enough area for large sized bruises.

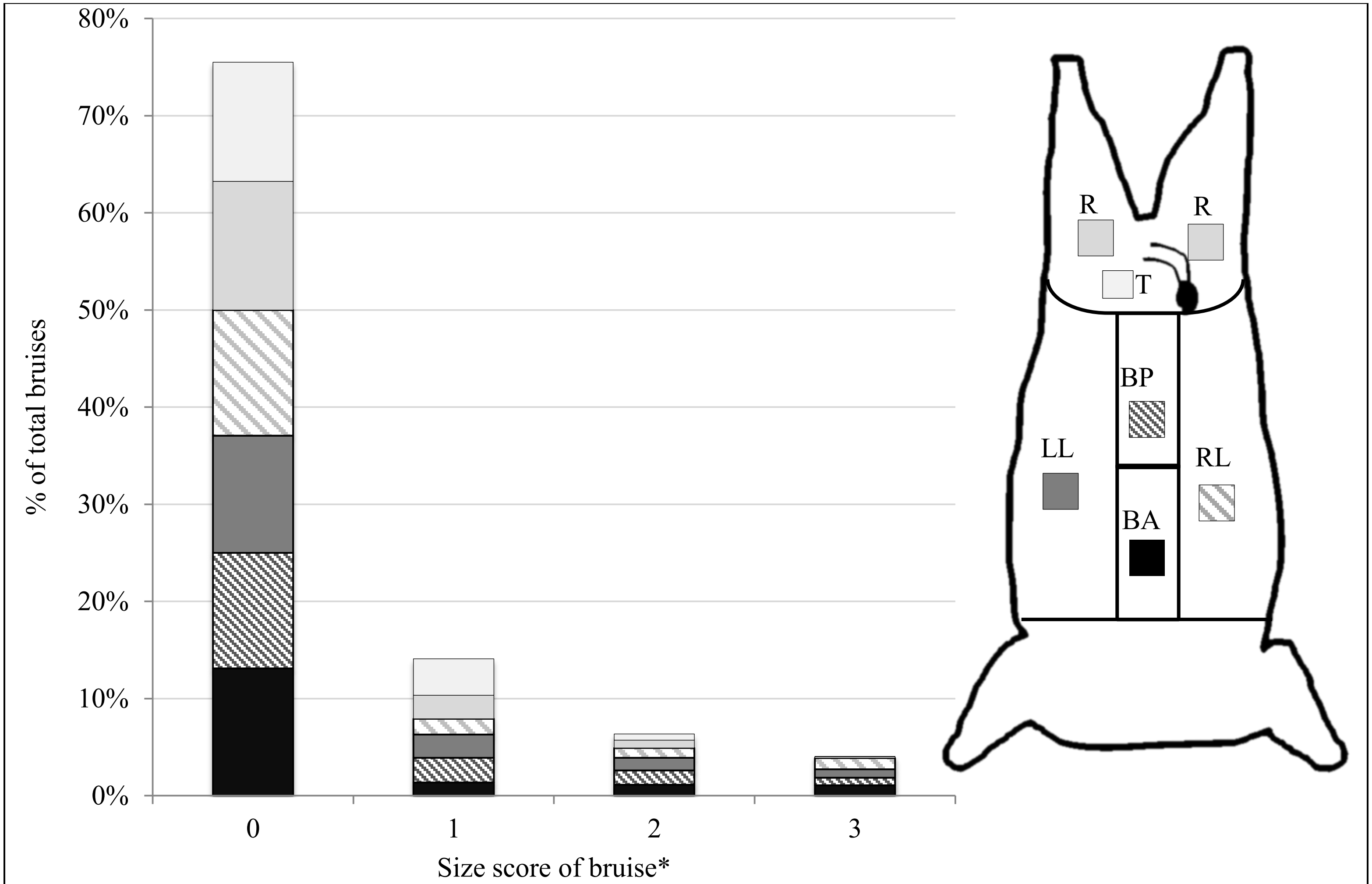

Figure 4.7 The distribution of bruises of each size score in each position on a carcass.

* The bruise size score of 1 is < 6.5 cm in diameter, size score 2 is 6.5 > 12 cm in diameter, and size score 3 is > 12 cm

4.4.3 Microclimate models

The microclimate models were used to determine which transport factors affect ΔTemp, ΔHR and ΔTHI. The factors tested were journey duration and compartment within the trailer. The ambient temperature, ambient HR and ambient THI were used as covariates. This relationship was tested for two periods during the journey (dynamic and steadystate). For each dependent variable analyzed, the 3-way interaction was significant. Table 4.7 reports the significance of each of the individual variables as well as the 2 and 3-way interactions, which are depicted in Figures 4.8, 4.9, 4.10, 4.11, 4.12 and 4.13. ΔTemp, ΔHR and ΔTHI all display a similar pattern with their corresponding ambient variable. As the ambient temp becomes colder (from 5 to -20 °C) the ΔTemp increases, indicating that the internal temp becomes higher than the external temp. As the ambient HR decreases (from 3.7 to 0.4 g water/kg dry air), the ΔHR increases, indicating that the air inside the trailer is more humid than outside the trailer when the outside air is dry. Similarly, as the ambient THI decreases (from 0 to -30 °C) the ΔTHI increases, indicating that the THI is greater inside the trailer than outside. This pattern is also influenced by the trailer compartment and the journey duration as is shown in Figures 4.8 to 4.13.

Table 4.7 The significance of factors affecting the microclimate of 36 trailers with five compartments and two journey durations (< 300 km or > 300 km) in one of two events (dynamic and steady state) during the journey of finished cattle from feedlot to slaughter facility during Canadian winter conditions.

Journey Event	Variable	Ambient Variable (AV)[1]	Compartment (C)	Journey Duration (JD)	AV*C	AV*JD	C*JD	AV*C*JD
Dynamic[2]	Δ Temp	<.0001	0.0266	<.0001	<.0001	<.0001	0.028	<.0001
	Δ HR	<.0001	0.0007	<.0001	<.0001	<.0001	0.2944	0.0009
	Δ THI	<.0001	0.0268	<.0001	<.0001	<.0001	0.1522	0.0068
Steady state[3]	Δ Temp	<.0001	0.0045	0.0059	<.0001	<.0001	0.3523	<.0001
	Δ HR	<.0001	<.0001	0.034	<.0001	0.3323	0.0006	<.0001
	Δ THI	<.0001	0.0048	0.0137	<.0001	<.0001	0.5229	0.0083

[1] The ambient variable associated with Δ temp is ambient temperature, with Δ HR is ambient humidity ratio and with Δ THI is ambient temperature humidity index
[2] The dynamic event is the first 60 min of travel
[3] The steady state event is the last 30 min of travel before arriving at the slaughter facility

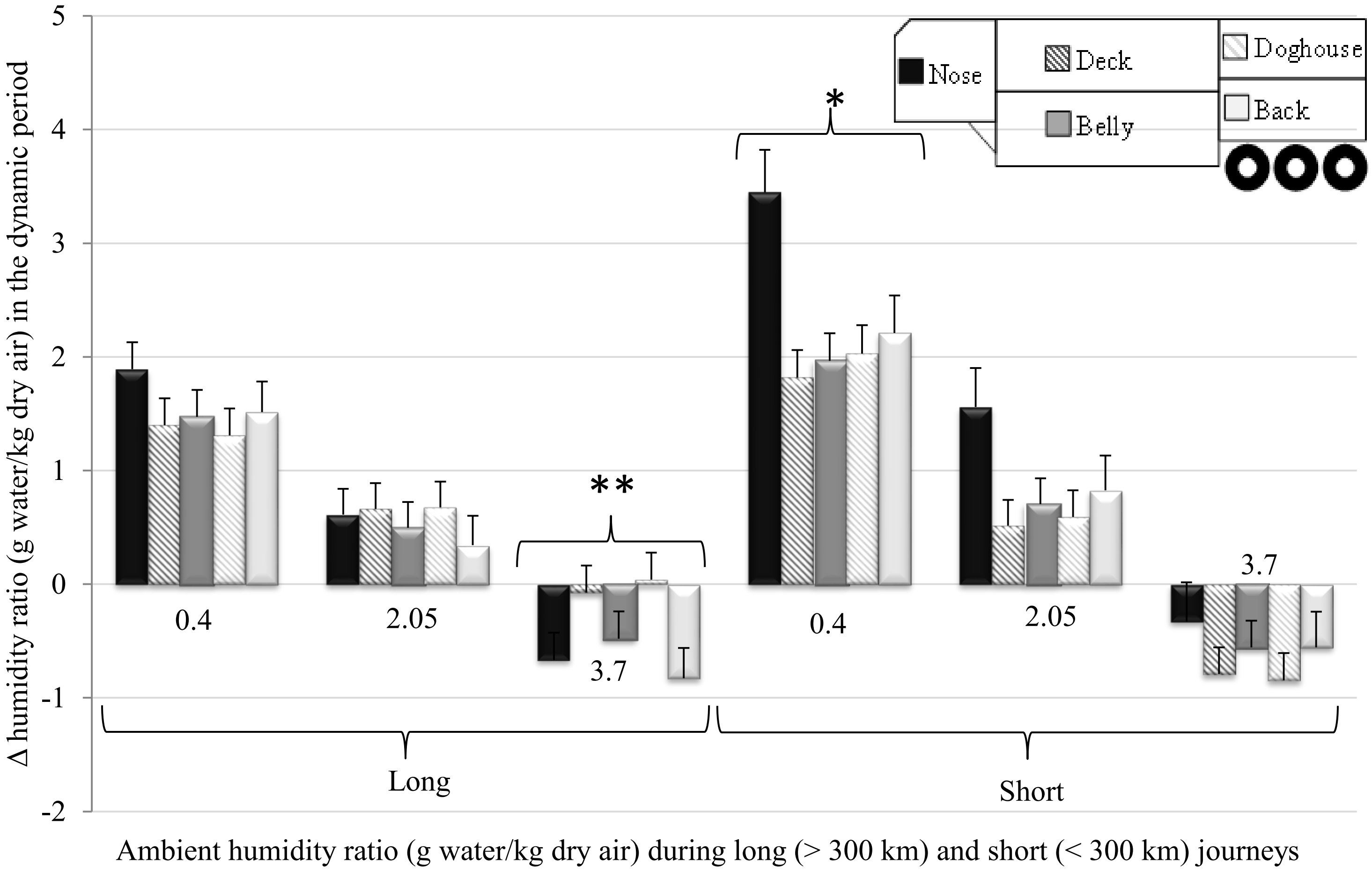

Figure 4.8 The three-way interaction of ambient humidity ratio, journey duration and compartment in the **dynamic period** (first 60 min of a journey) on **Δ humidity ratio** within a livestock trailer transporting finished cattle from

* Significant differences of means are indicated between the five compartments in a specific journey duration and ambient humidity ratio (*P* = 0.05) and trends at **(*P*=0.1)

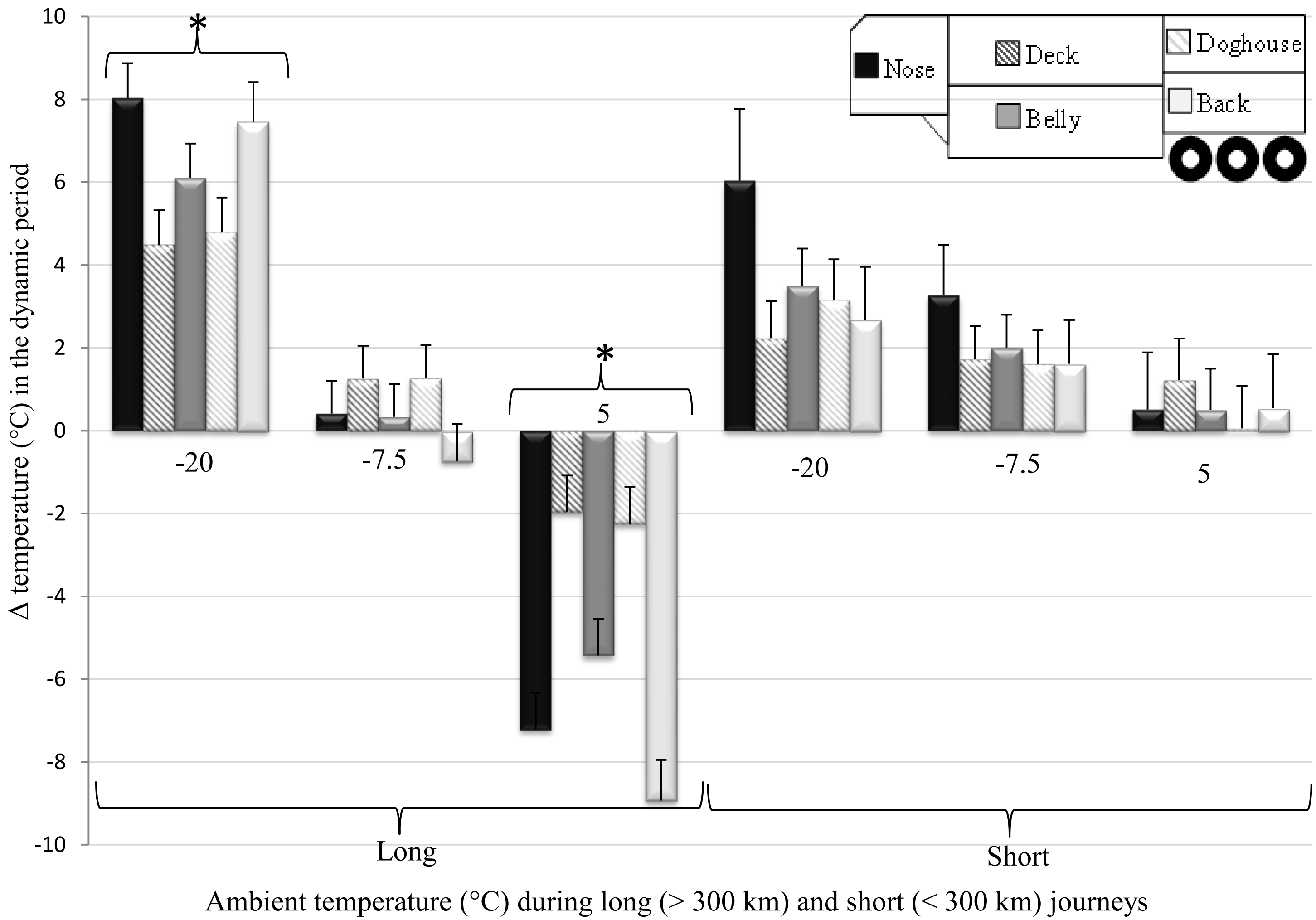

Figure 4.9 The three-way interaction of ambient temperature, journey duration and compartment in the **dynamic period** (first 60 min of a journey) on **Δtemperature** within a livestock trailer transporting finished cattle from feedlot to a slaughter plant in western Canadian winter conditions.

* Significant differences of means are indicated between the five compartments in a specific journey duration and ambient temperature ($P = 0.05$)

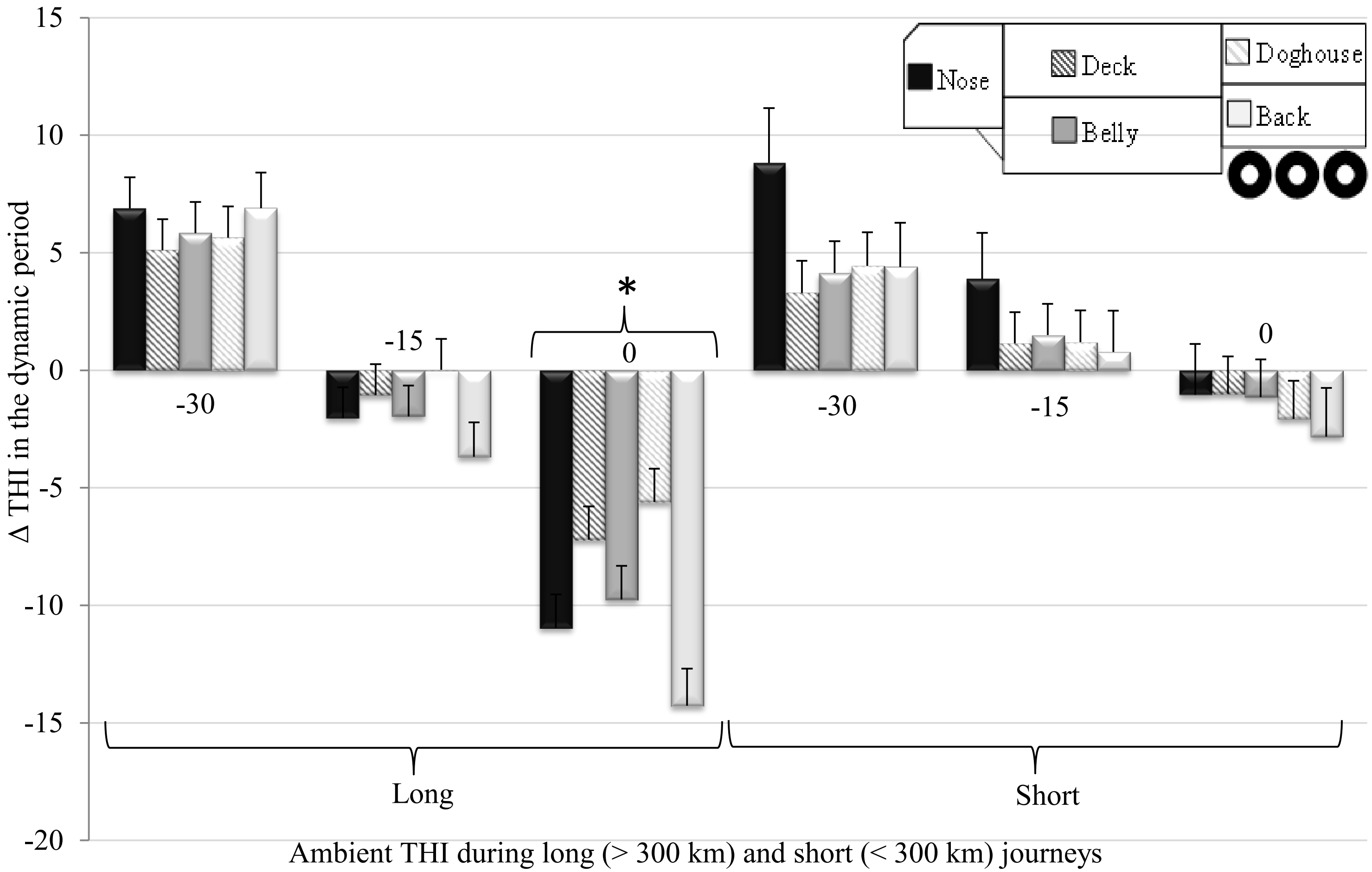

Figure 4.10 The three-way interaction of ambient THI, journey duration and compartment in the **dynamic period** (first 60 min of a journey) on **ΔTHI** within a livestock trailer transporting finished cattle from feedlot to a slaughter plant in western Canadian winter conditions.

* Significant differences of means are indicated between the five compartments in a specific journey duration and ambient THI ($P = 0.05$)

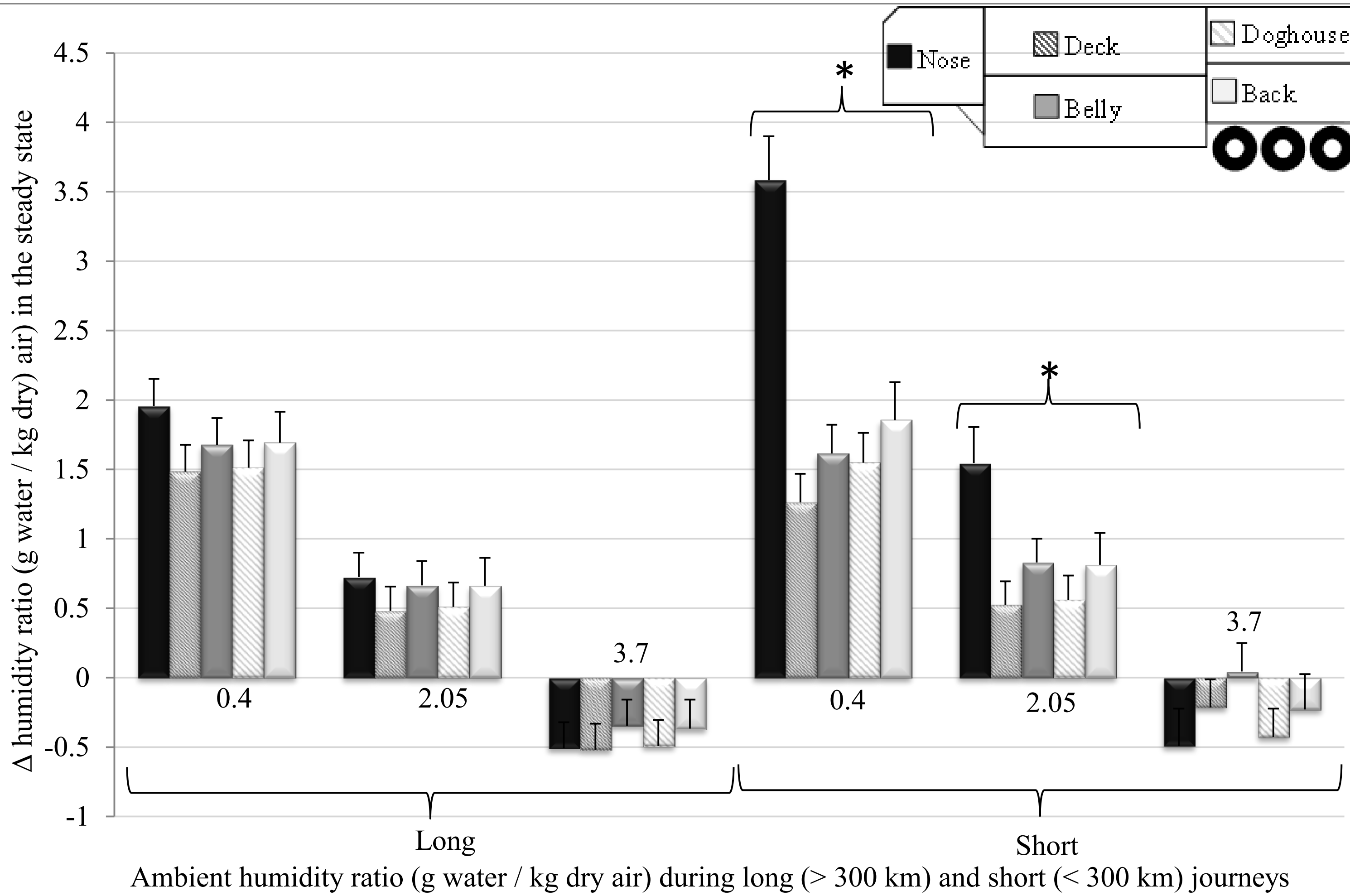

Figure 4.11 The three-way interaction of ambient humidity ratio, journey duration and compartment in the **steady state** (last 30 min of a journey) on **Δhumidity ratio** within a livestock trailer transporting finished cattle from feedlot to a slaughter plant in western Canadian winter conditions.

* Significant differences of means are indicated between the five compartments in a specific journey duration and ambient humidity ratio ($P = 0.05$)

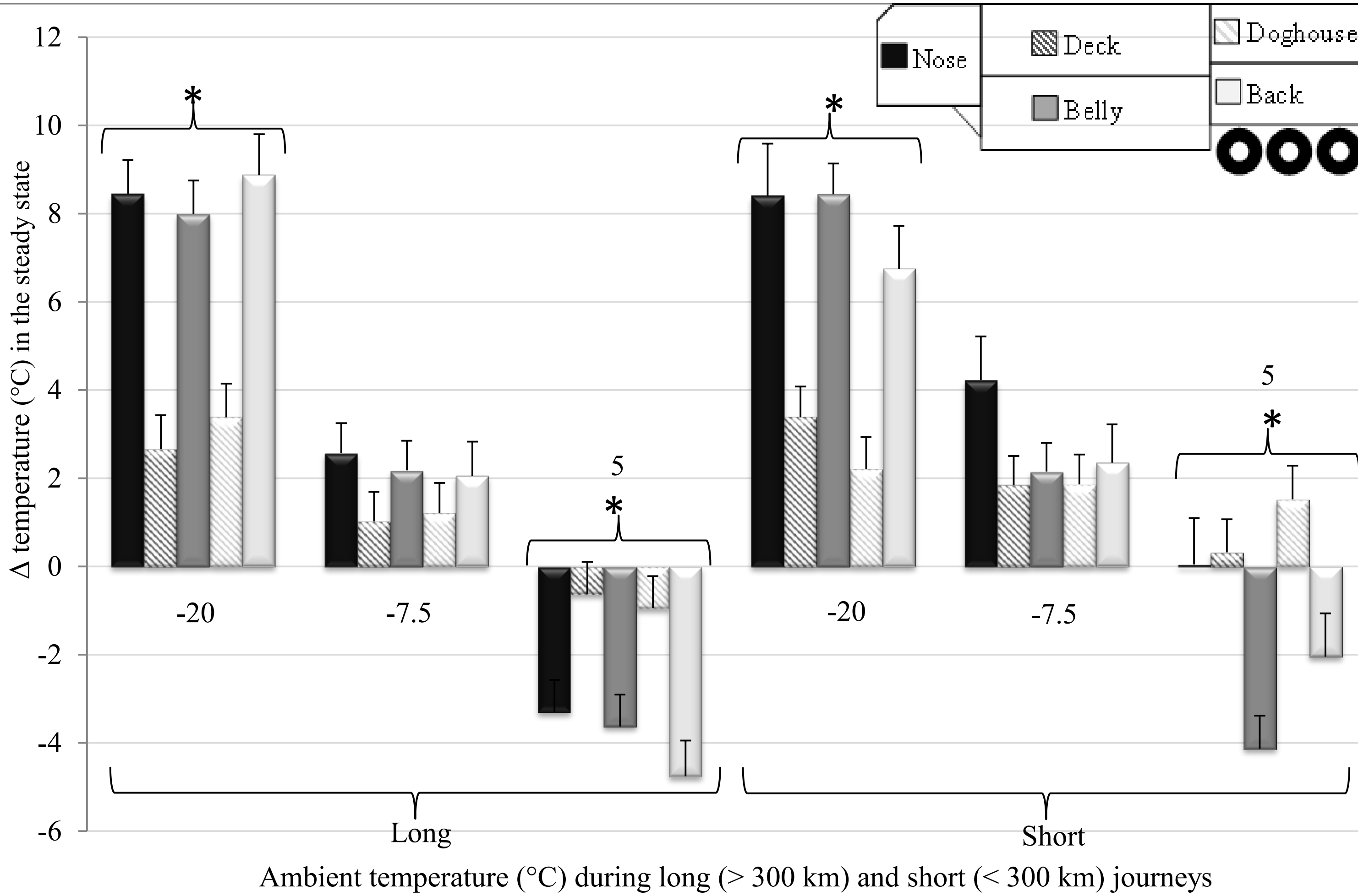

Figure 4.12 The three-way interaction of ambient temperature, journey duration and compartment in the **steady state** (last 30 min of a journey) on **Δ temperature** within a livestock trailer transporting finished cattle from feedlot to a slaughter plant in western Canadian winter conditions.

* Significant differences of means are indicated between the five compartments in a specific journey duration and ambient temperature (*P* = 0.05)

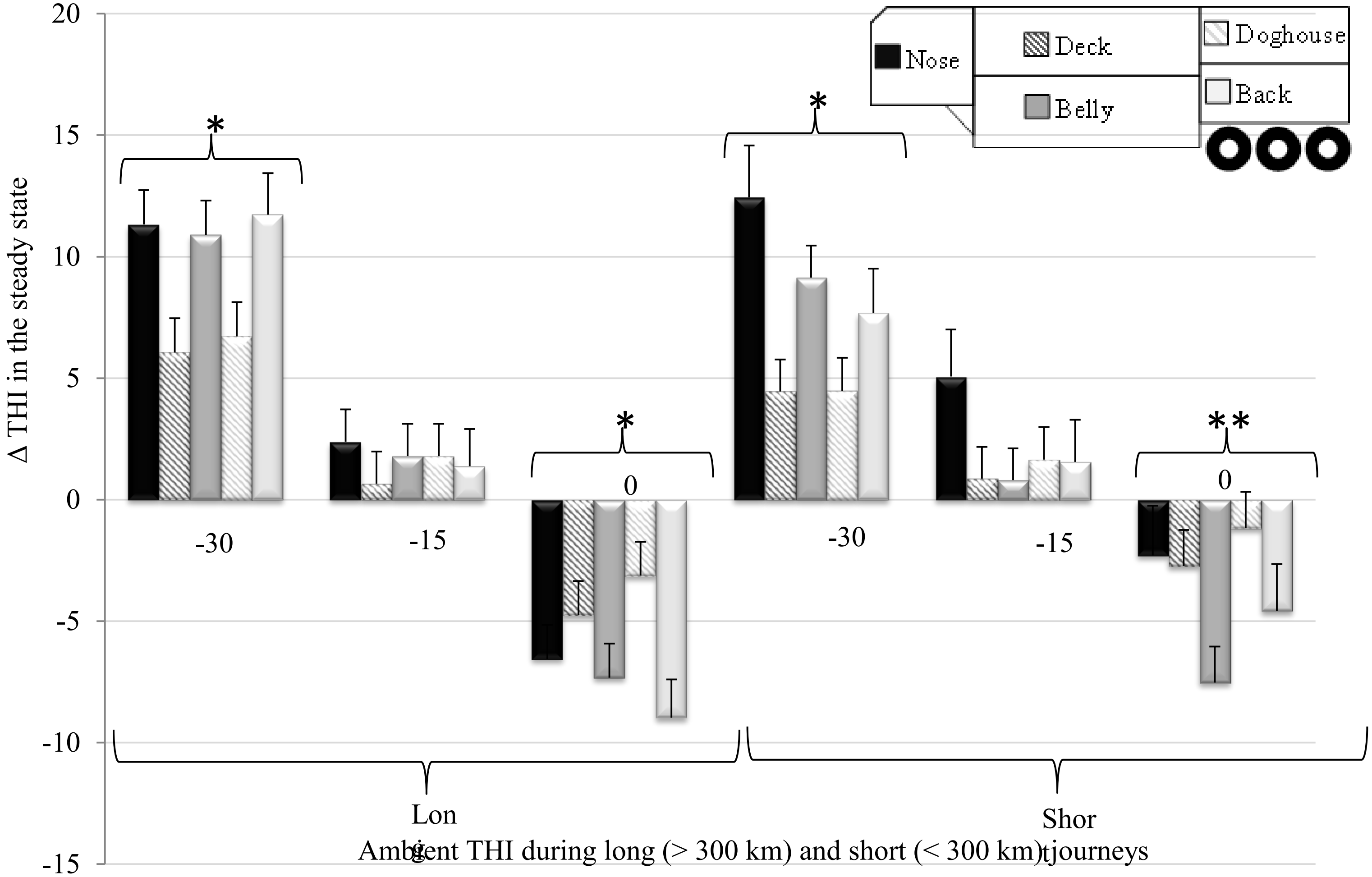

Figure 4.13 The three-way interaction of ambient THI, journey duration and compartment in the **steady state** (last 30 min of a journey) on **Δ THI** within a livestock trailer transporting finished cattle from feedlot to a slaughter facility in western Canadian winter conditions.

*Significant differences of means are indicated between the five compartments in a specific journey duration and ambient THI *(P = 0.05) and trends at **(P=0.1)

The effect of stationary trailer time and compartment on microclimate variables was also analyzed. The microclimate during the stationary period, from when the cattle arrived at the slaughter plant to when they began unloading (waiting time), was affected both by the amount of time the trailer stayed stationary and by the compartment within the trailer (Table 4.8). Figures 4.14, 4.15 and 4.16 show the relationship between ΔTemp, ΔHR and ΔTHI and waiting time for each compartment. The increased ΔTemp after 60 stationary min ranges from 5.12 to 10.92 °C. The increased ΔHR after 60 stationary min ranged from 1.47 to 2.43 g water/kg dry air. The increased ΔTHI after 60 stationary min ranged from 6.49 to 12.13.

Table 4.8 Factors affecting the microclimate of 36 trailers with five compartments while stationary at the slaughter facility following transport in Canadian winter conditions.

Variable	Compartment	Wait time	Wait time*wait time (WT^2)	Compartment* Wait time	Compartment* WT^2
ΔTemp	0.0002	< 0.0001	< 0.0001	< 0.0001	< 0.0001
ΔHR	0.0384	< 0.0001	< 0.0001	< 0.0001	< 0.0001
ΔTHI	0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

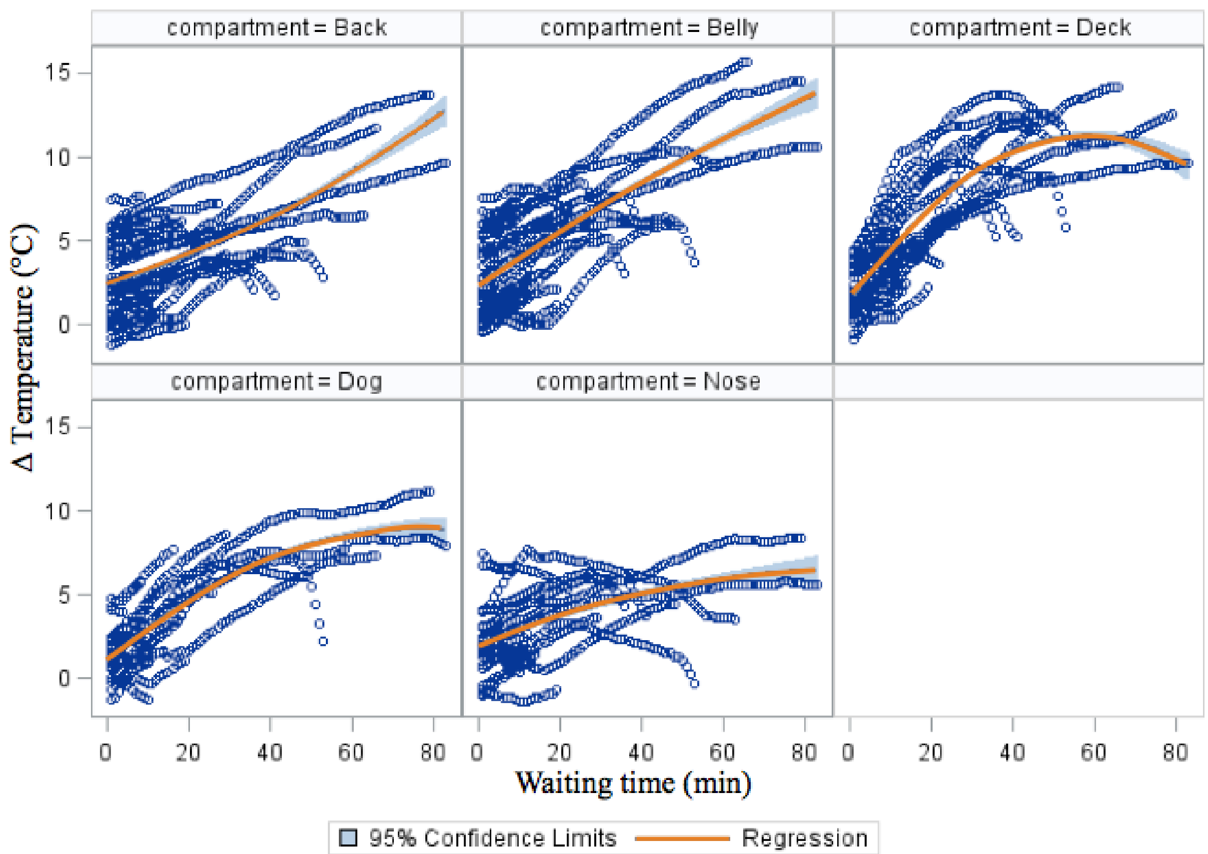

Figure 4.14 The effect of compartment and waiting time on the ΔTemperature within trailers holding finished cattle waiting at a slaughter plant to unload during Canadian winter conditions.

Back	$\Delta Temp = 2.34 + 0.085x + 0.0000074x^2$
Belly	$\Delta Temp = 2.59 + 0.12x - 0.00019x^2$
Deck	$\Delta Temp = 1.68 + 0.28x - 0.0021x^2$
Doghouse	$\Delta Temp = 1.32 + 0.21x - 0.0015x^2$
Nose	$\Delta Temp = 2.66 + 0.062x - 0.00035x^2$

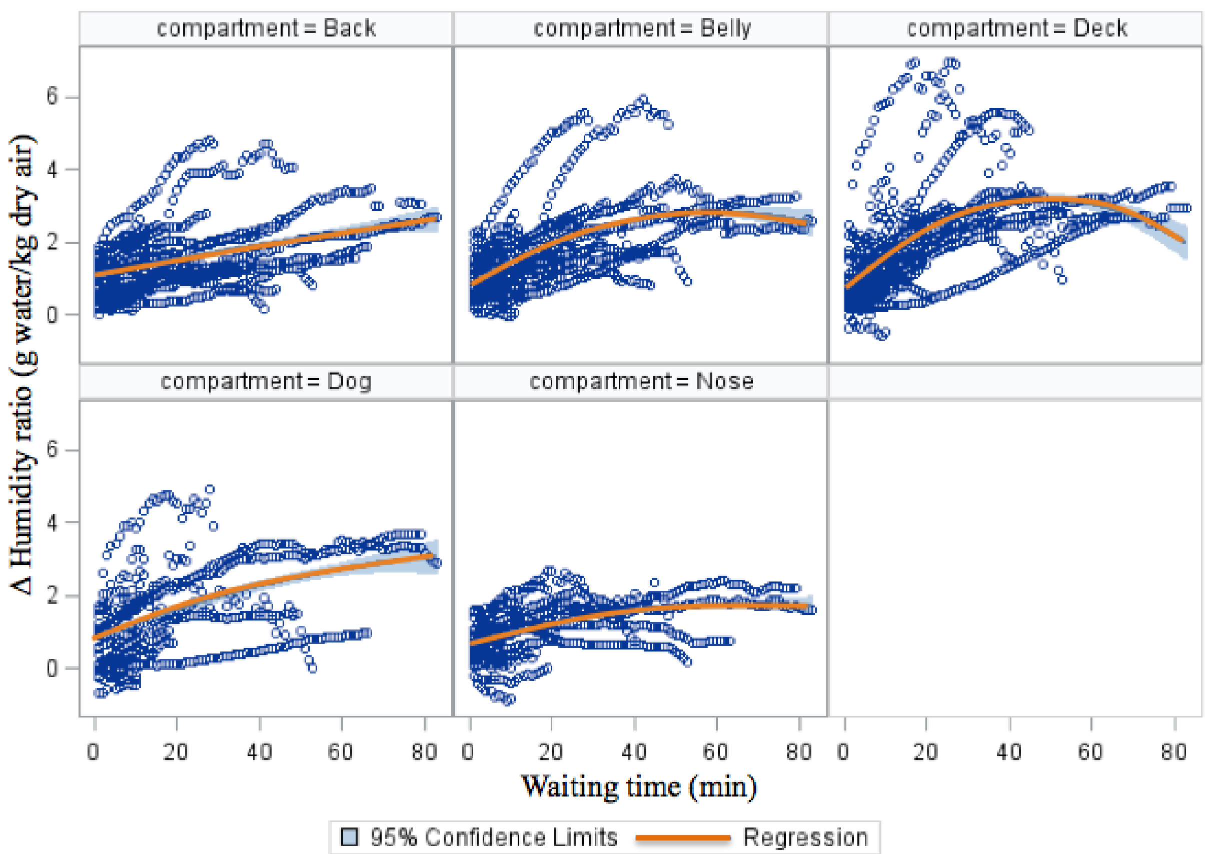

Figure 4.15 The effect of compartment and waiting time on the ΔHumidity ratio within trailers holding finished cattle waiting at a slaughter plant to unload during Canadian winter conditions.

Back	$\Delta HR = 0.94 + 0.033\ x - 0.00019\ x^2$
Belly	$\Delta\ HR = 0.78 + 0.069\ x - 0.00061x^2$
Deck	$\Delta\ HR = 0.66 + 0.096\ x - 0.00088\ x^2$
Doghouse	$\Delta\ HR = 0.63 + 0.054\ x - 0.0004x^2$
Nose	$\Delta\ HR = 0.56 + 0.029\ x - 0.00023x^2$

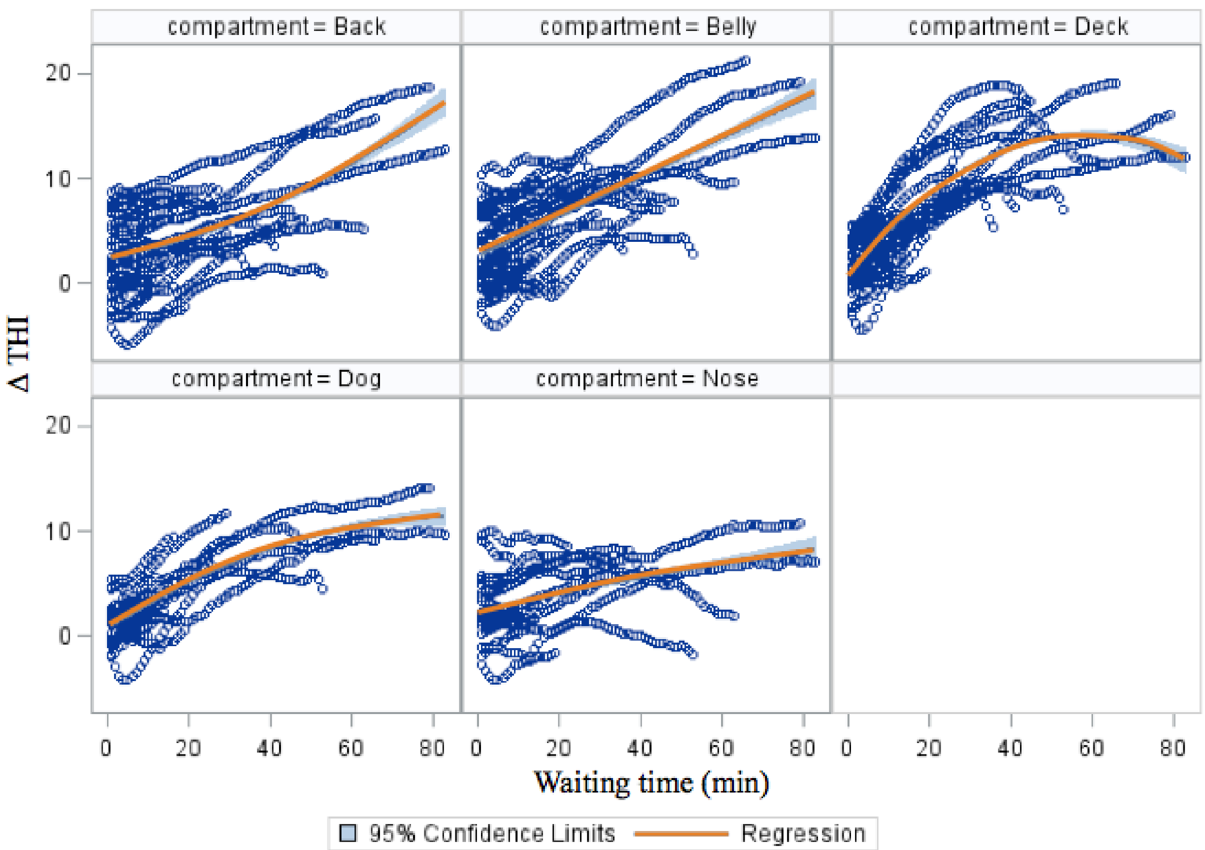

Figure 4.16 The effect of compartment and waiting time on the ΔTHI within trailers holding finished cattle waiting at a slaughter plant to unload during Canadian winter conditions.

Back	$\Delta THI = 2.15 + 0.11\ x + 0.00011\ x^2$
Belly	$\Delta\ THI = 2.61 + 0.16\ x - 0.00002\ x^2$
Deck	$\Delta\ THI = 1.11 + 0.40\ x - 0.0029x^2$
Doghouse	$\Delta\ THI = 0.84 + 0.30\ x - 0.002x^2$
Nose	$\Delta\ THI = 3.15 + 0.082\ x - 0.00044x^2$

4.4.4 Acceleration model

The speed of the trailer, compartment and journey duration were tested for their individual, 2-way and 3-way interaction effects on acceleration. The 3-way interaction was not significant in any axis of acceleration. The speed and compartment 2-way interaction as well as the journey duration and compartment 2-way interaction were significant in the horizontal axis. The journey duration and compartment 2-way interaction was significant in the lateral axis. The journey duration and trailer speed 2-way interaction was significant in the vertical axis. See Table 4.9 for more information on the significance of factors affecting acceleration.

When considering the horizontal axis the nose compartment experienced greater acceleration than other compartments at speeds above 10 km; below 10 km it experienced similar acceleration to the other compartments. In contrast the back compartment had the lowest acceleration of all the compartments except at the slowest speed (< 1 km/h). In fact, the back experienced the greatest acceleration when the trailer was moving at < 1 km/h. The nose compartment acceleration was more dependent on the speed of the trailer than the other four compartments of the trailer in the horizontal axis. During long journeys, the acceleration in the doghouse changed its pattern, as it was higher than in short journeys for both the horizontal and lateral axes. During long journeys, the vertical axes had the greatest acceleration at speeds of < 1 km/h, whereas, during short journeys, the vertical axes had the highest acceleration at the fastest trailer speed The vertical acceleration was not affected by compartment while the lateral acceleration was not affected by the speed of the trailer (Table 4.9).

Table 4.9 Significance of factors affecting the rms of acceleration (m/s^2) in three axes of motion of 33 trailers with five compartments and two journey durations transporting finished cattle from a feedlot to the slaughter facility during Canadian winter conditions.

	Speed (S)	Compartment(C)	Journey Duration (JD)	S*C	JD*C	JD*S
Y-axis rms (m/s^2)[1]	0.5319	< 0.0001	0.1489	0.0005	< 0.0001	0.911
Z-axis rms (m/s^2)[2]	0.0673	< 0.0001	0.0421	0.8608	< 0.0001	0.2017
X-axis rms (m/s^2)[3]	0.0067	0.5795	0.1429	0.7846	0.2631	0.0315

[1] Y-axis measures horizontal acceleration within the trailer (front to back)

[2] Z-axis measures lateral acceleration within the trailer (side to side)

[3] X-axis measures vertical acceleration within the trailer (up and down)

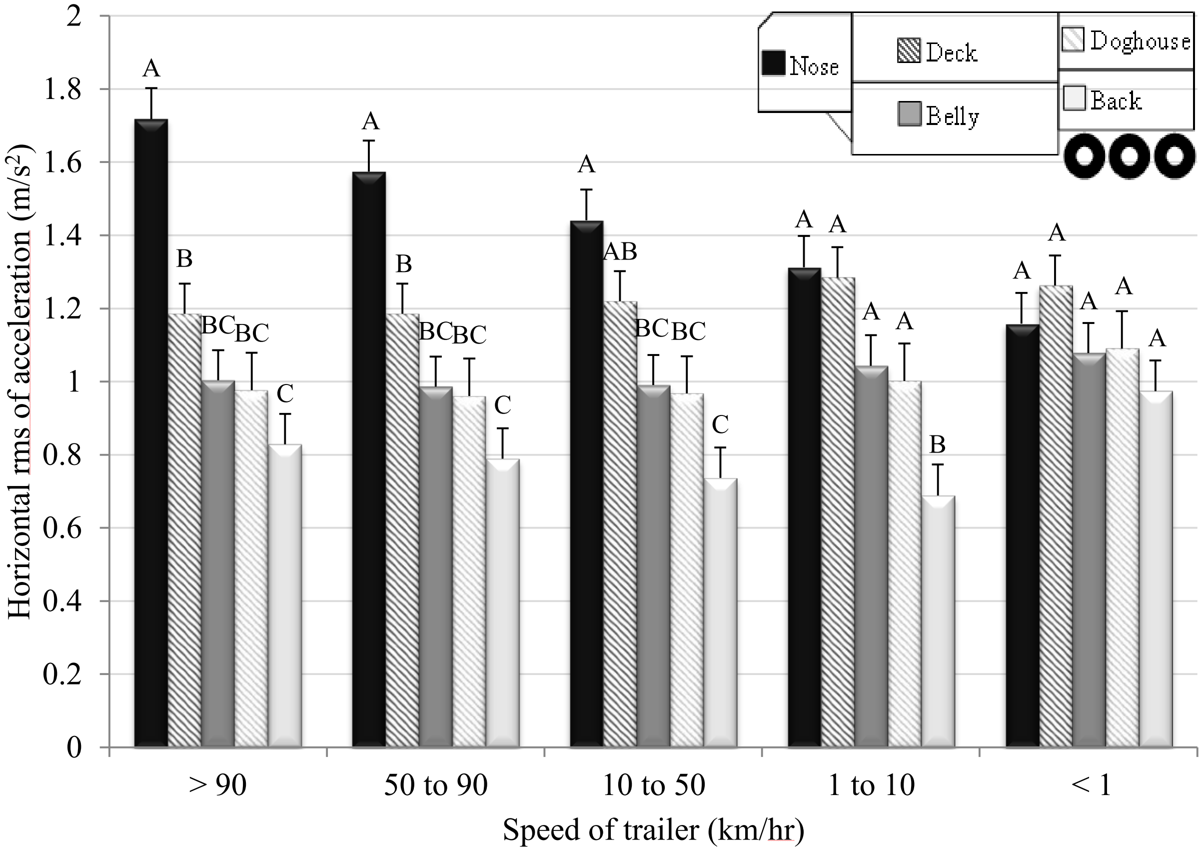

Figure 4.17 The interaction of trailer compartment and speed of trailer on Y-axis (horizontal motion) of 33 trailers transporting fat cattle from feedlot to slaughter facility in

[ABC] Bars with different superscripts differ within a speed category (*P* < 0.05)

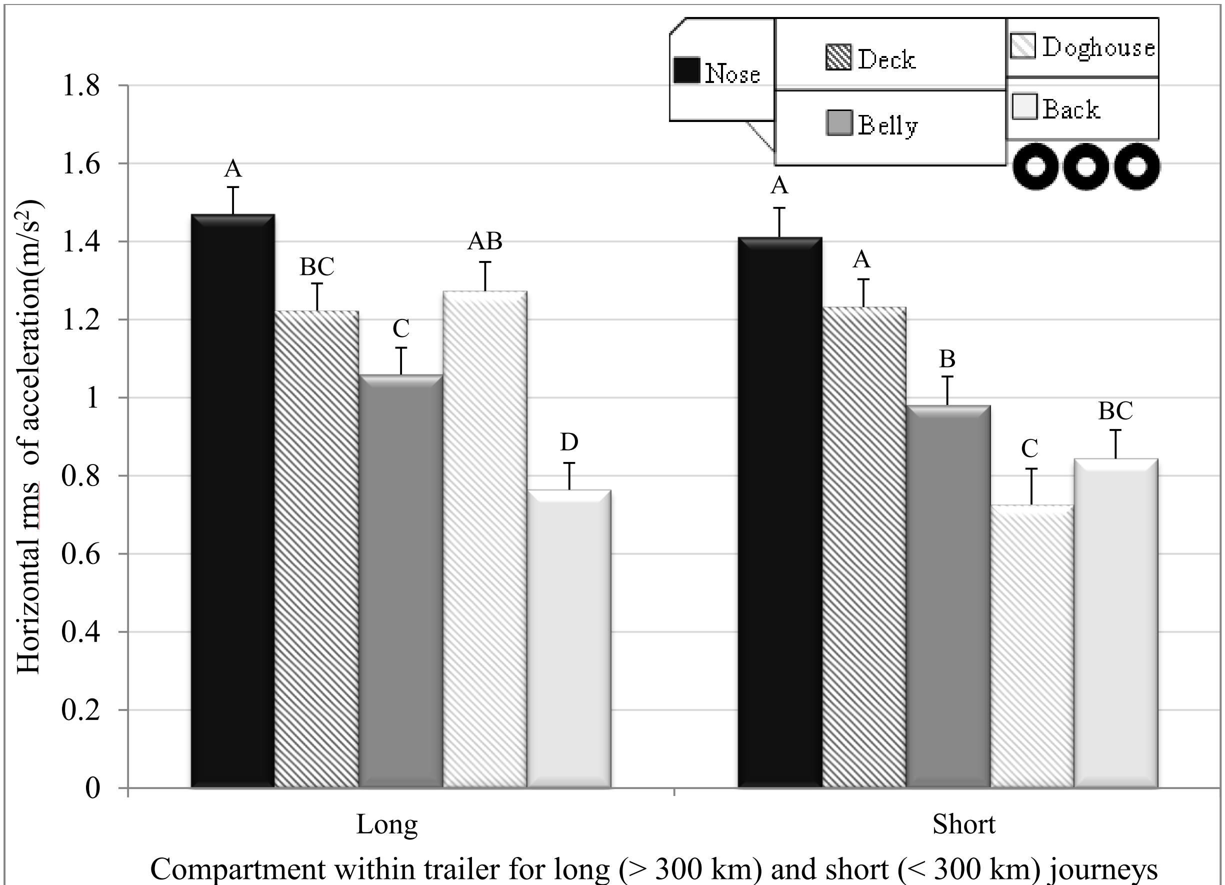

Figure 4.18 The interaction of trailer compartment and journey duration on Y-axis (horizontal motion) of 33 trailers transporting fat cattle from feedlots to a slaughter facility in Canadian winter conditions.

^{ABC} Bars with different superscripts differ within a journey duration ($P < 0.05$)

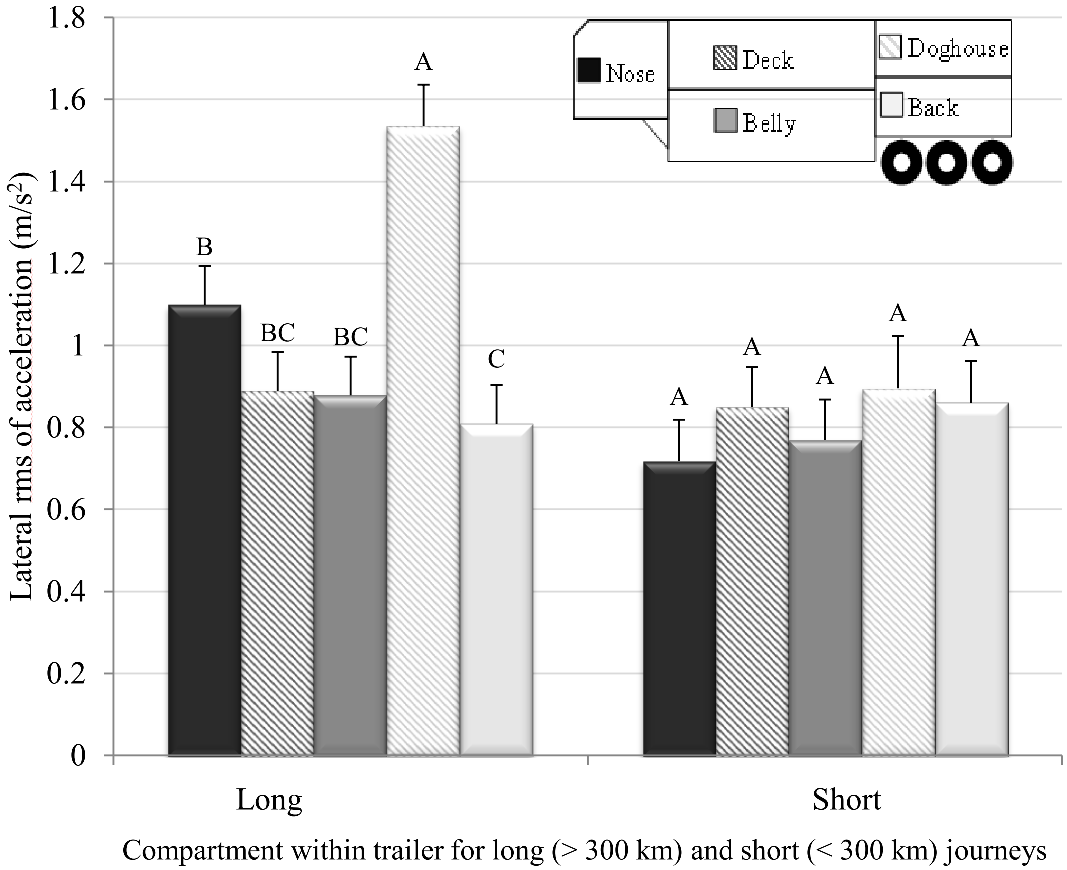

Figure 4.19 The interaction of trailer compartment and journey duration on Z-axis (lateral motion) of 33 trailer loads transporting fat cattle from feedlots to a slaughter facility in Canadian winter conditions.

^{ABC} Bars with different superscripts differ within a journey duration ($P < 0.05$)

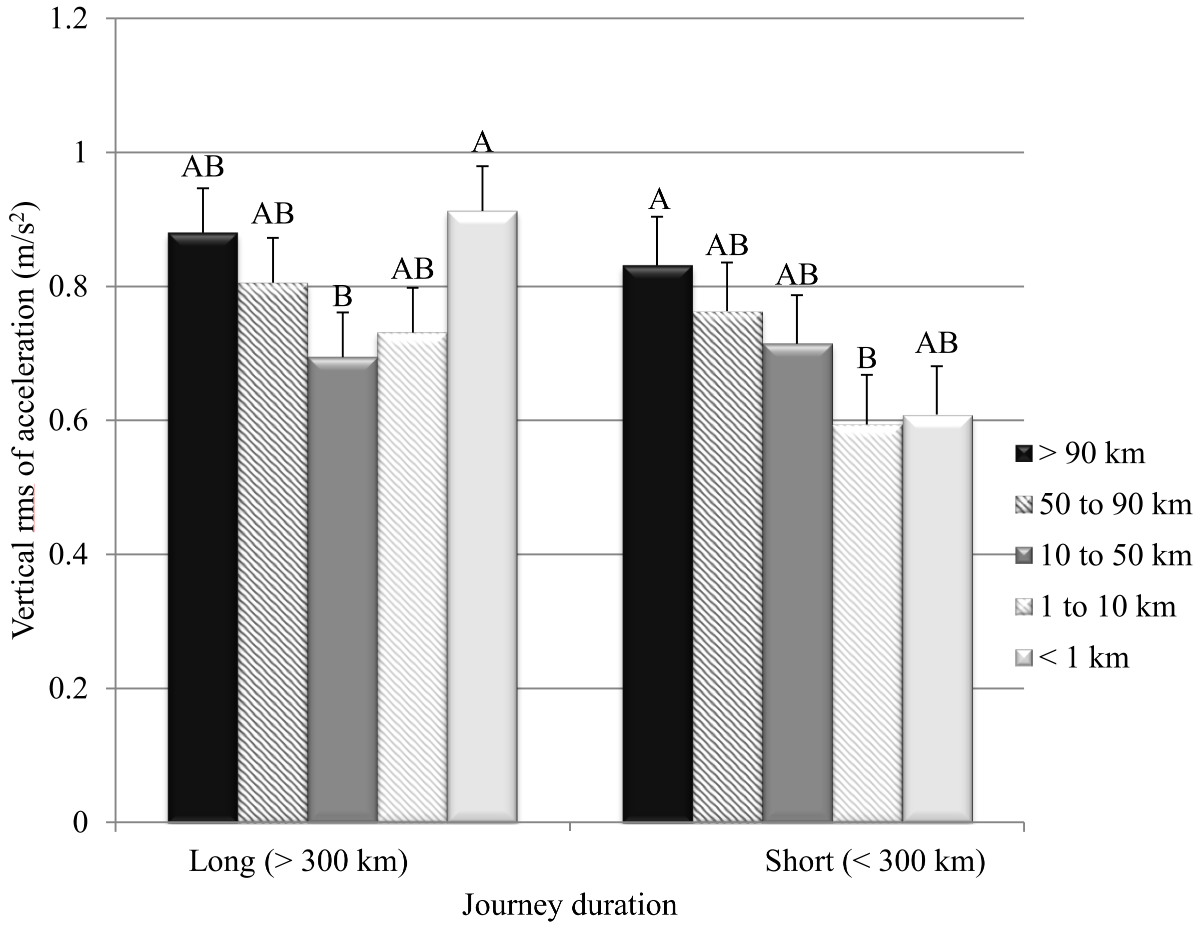

Figure 4.20 The interaction of journey duration and trailer speed on X-axis (Vertical motion) of 33 trailers transporting fat cattle from feedlots to a slaughter facility in Canadian winter conditions.

[ABC] Bars with different superscripts differ within a journey duration ($P < 0.05$)

4.4.5 Shrink model

There were four variables that affected shrink in this study; journey duration ($P < 0.001$), allometric coefficient (k) ($P < 0.001$), mean THI ($P < 0.001$) and electric prod use at loading ($P = 0.0012$). When combined into a multivariable regression model they resulted in a coefficient of determination of 0.856 ($P < 0.001$). Table 4.10 lists the intercepts and slopes with standard errors in the individual regressions (Models 1 - 4) as well as the multivariable regression (Model 5). Long journey durations had higher shrink ($P < 0.001$) by approximately 1% (Figure 4.21). The shrink increased with greater k-value ($P < 0.001$) by 2.56% over a range in k-values of 0.03 (Figure 4.22). The shrink increased at THI values closer to zero ($P < 0.001$) by 2.28% over a change in THI of 40 (Figure 4.23). Unexpectedly, the shrink decreased with increased prodding at loading ($P < 0.001$) by 1.85% between loads that had 25 animals prodded and loads that had 0 animals prodded (Figure 4.24).

Table 4.10 The factors in the model explaining shrink (average % of body weight loss on trailer) with standard errors.

	Intercept % shrink (SE)	Slope of journey duration	Slope of maximum k	Slope of mean THI	Slope of number of electric prod use at loading	R^2	RMS (shrink units)	P-value
Simple Regression								
Model 1	2.921 (0.174)	-1.472 (0.239)	-	-	-	0.56	0.67	<0.001
Model 2	-0.516 (0.555)	-	85.424 (17.324)	-	-	0.448	0.755	<0.001
Model 3	3.186 (0.249)	-	-	0.057 (0.011)	-	0.453	0.751	<0.001
Model 4	2.842 (0.256)	-	-	-	-0.074 (0.021)	0.317	0.864	0.0012
Multiple Regression								
Model 5	2.596 (0.523)	-0.994 (0.211)	25.782 (13.288)	0.024 (0.008)	-0.033 (0.012)	0.856	0.42	<0.001

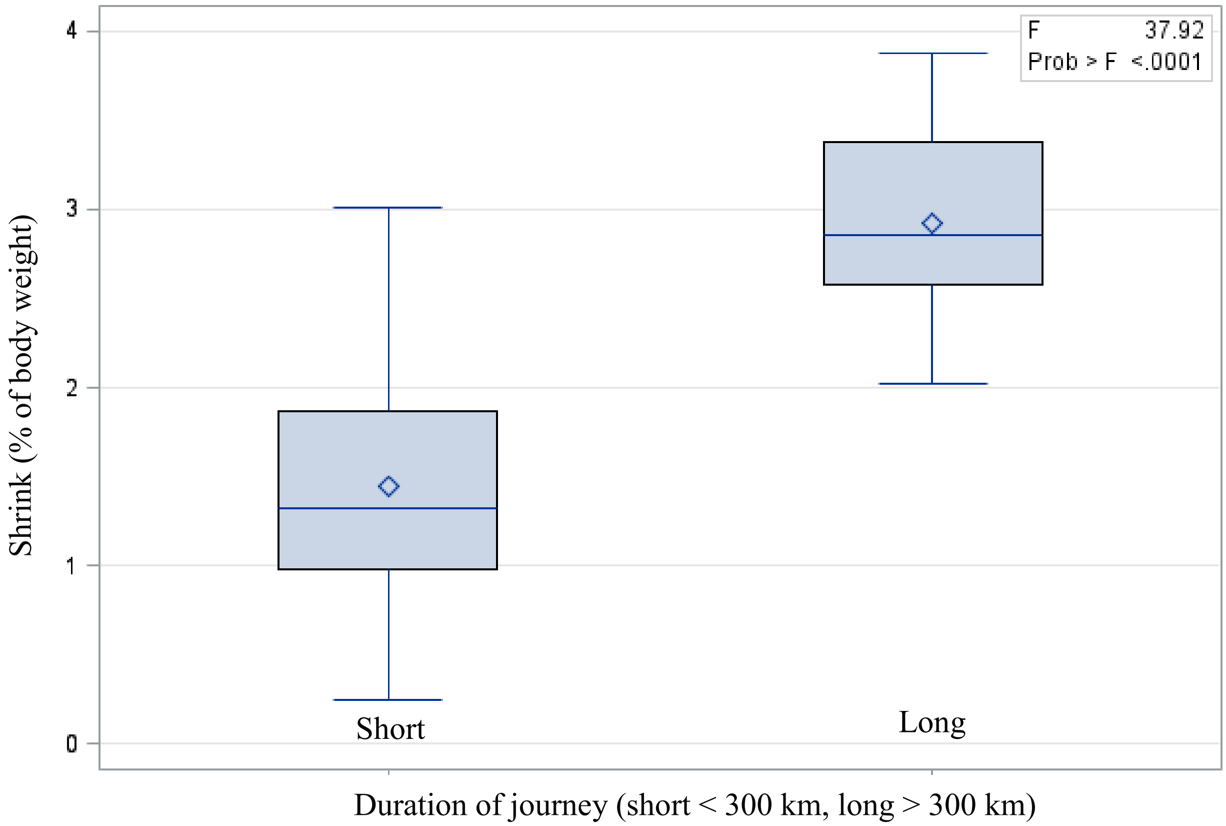

Figure 4.21 The effect of journey duration on the shrink (% of body weight) of finished cattle being transported on 32 loads from feedlot to slaughter facility in Canadian winter conditions.

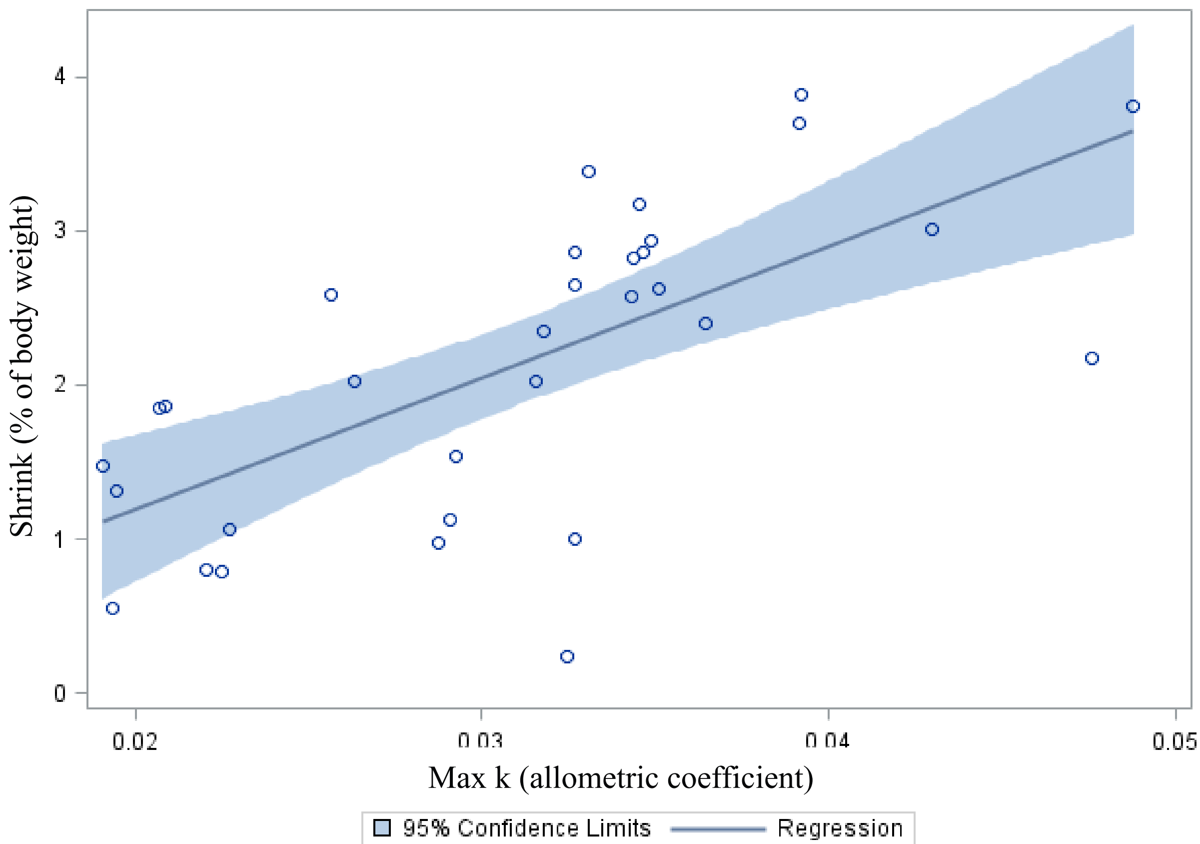

Figure 4.22 The effect of max k during the journey on the shrink (% of body weight) of finished cattle being transported on 32 loads from feedlot to slaughter facility in Canadian winter conditions.

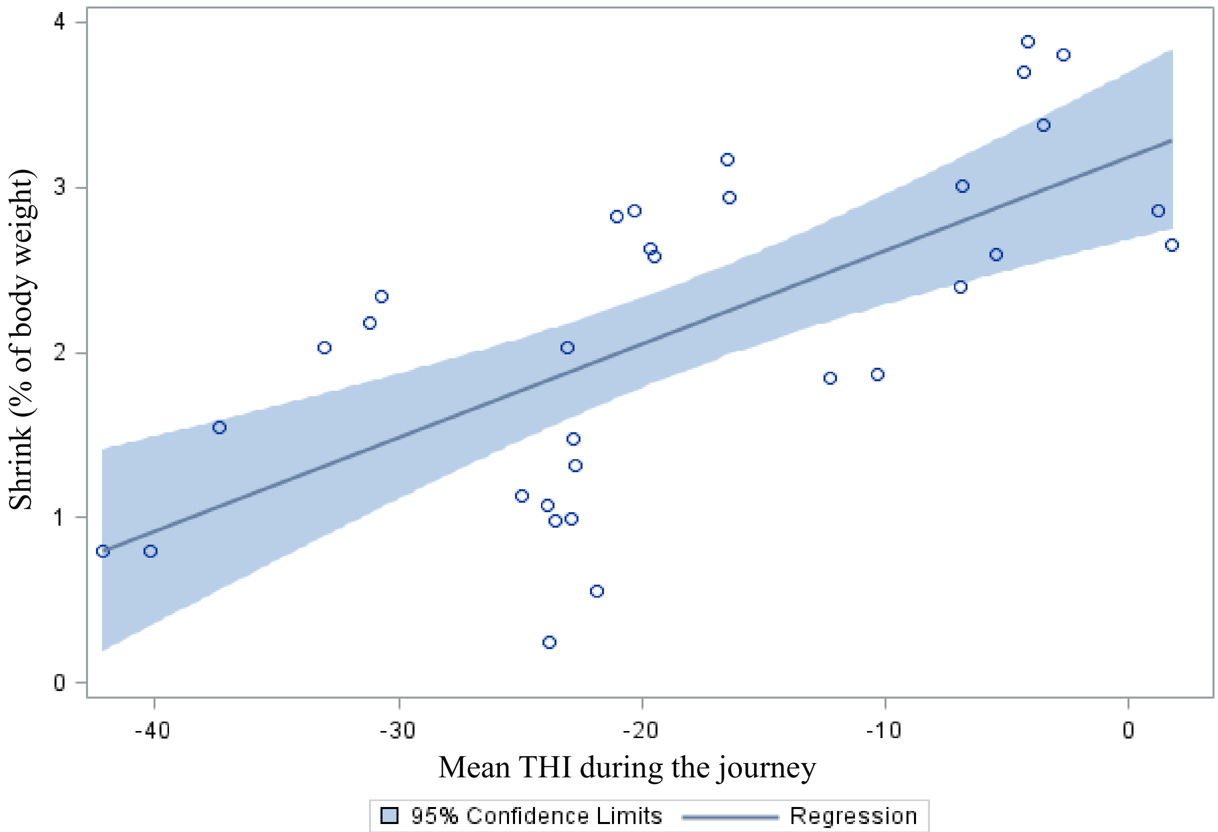

Figure 4.23 The effect of mean THI during the journey on the shrink (% of body weight) of finished cattle being transported on 32 loads from feedlot to slaughter facility in Canadian winter conditions

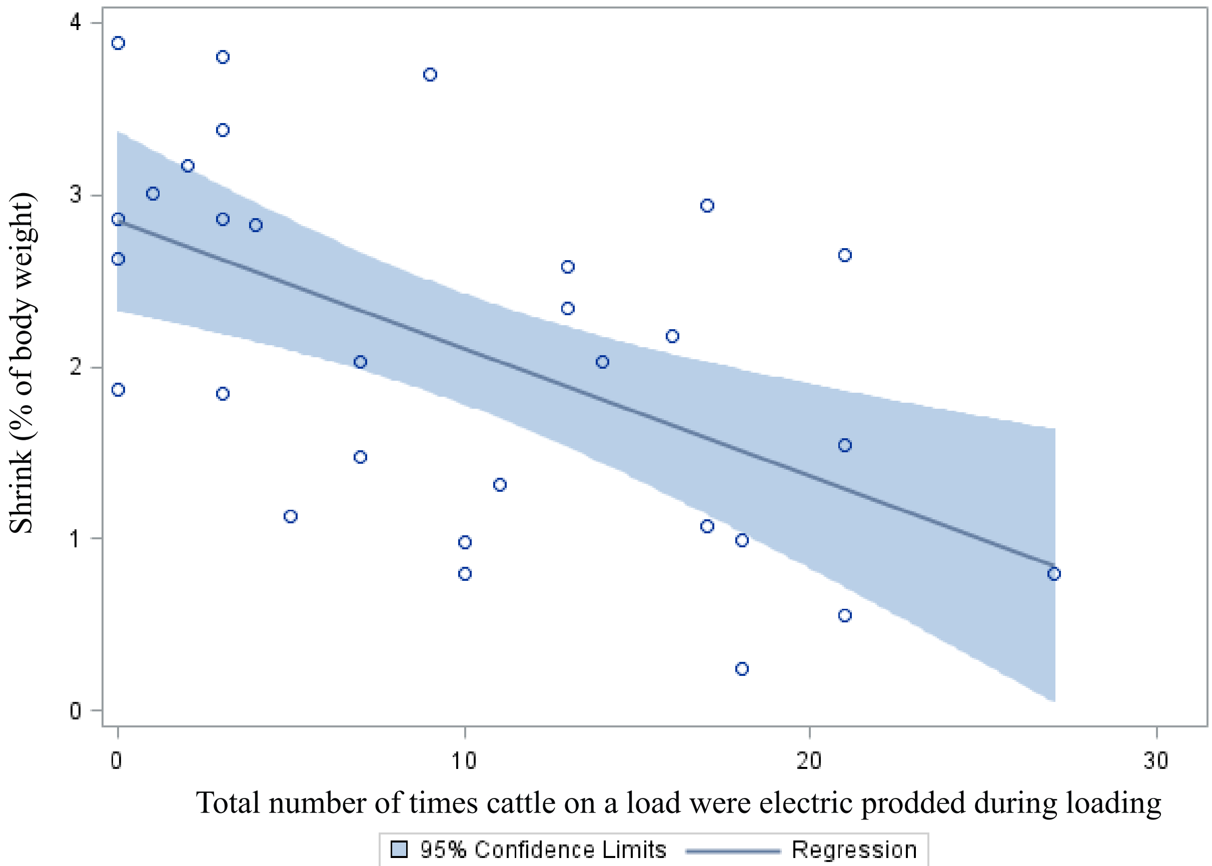

Figure 4.24 The effect of electric prodding during loading on the shrink (% of body weight) of finished cattle being transported on 32 loads from feedlot to slaughter facility in Canadian winter conditions.

4.4.6 Bruising model

Bruising was recorded on 1552 cattle from 36 loads but only 864 cattle remained in the final model for severe bruising (bruise score 3). Table 4.11 lists the independent variables used for initially testing their effect on severe bruising. Variables only remained in the final model if they were significant below $P < 0.1$. The variables that remained in the final multivariable model are listed in Table 4.12 with their odds ratios and *P* values. The two-way interaction of yield grade and position of bruises on the carcass ($P = 0.0025$) is depicted in Figure 4.2. This interaction suggests that severe bruising in different positions on the carcass is dependent on the yield of the animal, for example the anterior of the back on cattle has higher odds of severe bruising in animals with a yield grade of 1 (leaner) than animals with a yield grade of 3 (less lean). There was more variation in the odds of severe bruising between carcass positions in Y1 than yield grade 3. In the current study, when total wait time (Table 4.1) increased by an hour the odds of severe bruising decreased (OR = 0.8; $P < 0.0052$). Whereas, the odds of severe bruising increased when x-axis rms increased by 1 m/s^2 (OR = 1.81; $P < 0.0054$). The odds of severe bruising increased (OR = 1.59; $P < 0.032$) when cattle were not given beta agonists compared to when they were. Lairage time and unloading speed were significant when univariable analysis was conducted but became insignificant once included in the multivariable model and were therefore removed from the final model. Most of the microclimate variables were significant ($P < 0.1$) when analyzed individually but only two could be included in the final model because of co-linearity and neither remained significant ($P < 0.05$) in the multivariable model.

Table 4.11 Univariable analysis evaluating the effect of each individual variable on severe bruising of finished cattle (n=864) transported from feedlot to slaughter facility in Canadian winter conditions[1]

Variable	P value[2]	Type	Variable	P value[2]	Type
Position on carcass	< 0.0001	Categorical	Max prod use before stunning	0.7806	Continuous
Compartment	0.3164	Categorical	X-axis rms	0.0634	Continuous
Beta-agonist	0.0982	Categorical	Y-axis rms	0.9567	Continuous
Sex	0.0464	Categorical	Z-axis rms	0.3125	Continuous
Journey duration	0.9068	Categorical	Mean temperature (during the journey)	0.0783	Continuous
k	0.8899	Categorical	Mean humidity Ratio (during the journey)	n/a[3]	Continuous
DRSA	0.7216	Categorical	Mean THI (during the journey)	0.0841	Continuous
Waiting time	0.9165	Continuous	Maximum temperature (during the journey)	0.0766	Continuous
Wait time to unload	0.8847	Categorical	Maximum humidity Ratio (during the journey)	n/a[3]	Continuous
Lairage time	0.0652	Continuous	Maximum THI (during the journey)	0.0672	Continuous
Lairage time	0.1485	Categorical	Minimum temperature (during the journey)	0.0799	Continuous
Total wait time	0.0493	Continuous	Minimum humidity Ratio (during the journey)	0.0535	Continuous
Total wait time	0.0494	Categorical	Minimum THI (during the journey)	0.0743	Continuous
Load score (Maria et al. 2008)	0.89	Categorical	Minimum temperature (during waiting)	0.0543	Continuous
Unload score (Maria et al. 2008)	0.3146	Categorical	Minimum humidity Ratio (during waiting)	0.0929	Continuous
AMI criteria 5 (prodding during loading)	0.6902	Categorical	Minimum THI (during waiting)	0.0599	Continuous
Yield grade	0.0147	Categorical	Maximum temperature (during waiting)	0.0431	Continuous
Loading speed (Warren et al. 2010)	0.2047	Categorical	Maximum humidity Ratio (during waiting)	0.2239	Continuous
Unloading speed (Warren et al. 2010)	0.0631	Categorical	Maximum THI (during waiting)	0.0506	Continuous
Load score (Warren et al. 2010)	0.7005	Categorical	Mean temperature (during waiting)	0.0447	Continuous
Unload score (Warren et al. 2010)	0.7211	Categorical	Mean humidity Ratio (during waiting)	0.2202	Continuous
AMI criteria 4 (falling during loading)	0.9946	Categorical	Mean THI (during waiting)	0.0554	Continuous
AMI criteria 4 (falling during unloading)	0.5457	Categorical			

[1]Variables were included in the final multivariate model at a significance of $P < 0.1$
[2]An analysis was done to detect co-linearity between variables, if co-linearity was found only one of the co-linear variables was used in the final multivariate model
[3]The model did not converge

Table 4.12 Final multivariable model predicting the likelihood of severe bruising in finished cattle transported from feedlot to slaughter facility in Canadian winter conditions.[1]

Variable	*P* value	Category	Least squares means estimate	Odds	Odds ratio (95 % CL)
Position	<0.0001	BA	-3.14	0.04	0.81 (0.52- 1.25)
		BP	-3.35	0.04	0.65 (0.41 - 1.03)
		LL	-3.09	0.05	0.84 (0.56 - 1.27)
		RL	-4.70	0.01	0.17 (0.08 - 0.34)
		RL	-2.92	0.05	Reference
Yield grade	0.4084	-	-	-	-
Position x Yield grade	0.0025	BA, 1	-2.23	0.11	23.94 (5.71 - 100.43)
		BP, 1	-2.61	0.07	16.48(3.88 - 69.98)
		LL, 1	-2.97	0.05	11.49 (2.66 - 49.65)
		RL, 1	-3.08	0.05	10.3 (2.368 - 44.79)
		R, 1	-5.41	0.00	Reference
Position x Yield grade	0.0025	BA, 2	-3.51	0.03	2.49 (0.86 - 7.2)
		BP, 2	-3.60	0.03	2.27 (0.77 - 6.65)
		LL, 2	-3.01	0.05	4.08 (1.49 - 11.15)
		RL, 2	-2.75	0.06	5.28 (1.97 - 14.13)
		R, 2	-4.42	0.01	Reference
Position x Yield grade	0.0025	BA, 3	-3.68	0.03	1.79 (0.51 - 6.28)
		BP, 3	-3.85	0.02	1.52 (0.42 - 5.54)
		LL, 3	-3.30	0.04	2.62 (0.8 - 8.58)
		RL, 3	-2.94	0.05	3.78 (1.21 - 11.82)
		R, 3	-4.27	0.01	Reference
Beta agonist	0.0323	No	-3.21	0.04	1.588 (1.040 - 2.426)
		Yes	-3.67	0.03	Reference
Total wait time[2]	0.0052	-	-0.22	-	0.8 (0.68 – 0.94)
X-axis rms (m/s^2)[3]	0.0054	-	0.59	-	1.81 (1.19 - 2.75)

[1] The total frequency of severe bruising (bruise score 3) on all carcasses is 0.0509 (5.09 %)

[2] The odds ratio for total wait time is based on a change of 60 min

[3] The odds ratio for x-axis rms is based on a 1 unit change (1 m/s^2)

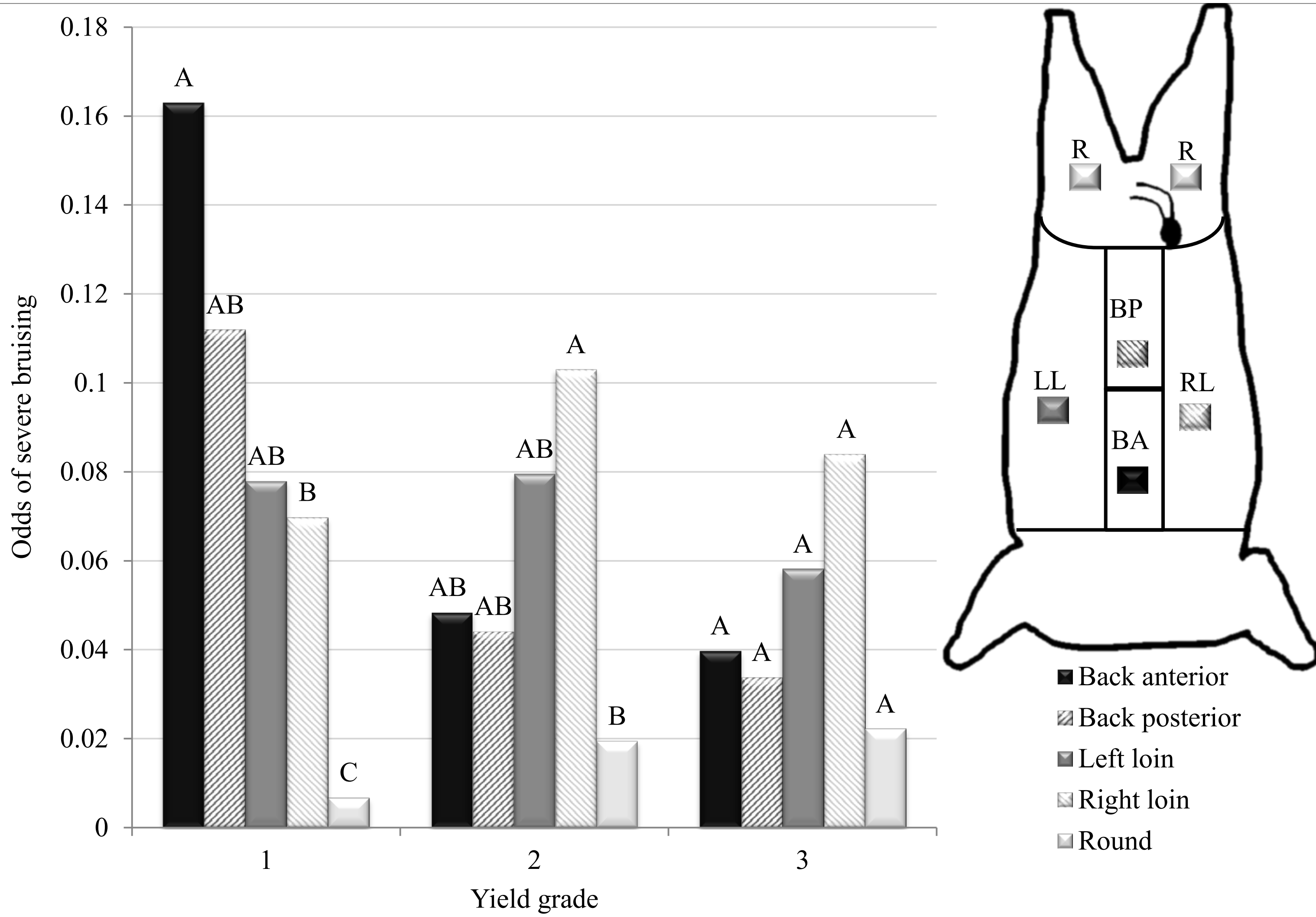

Figure 4.25 The effect of the interaction of yield grade and carcass position on the odds of severe bruising in finished

[ABC] Bars with different superscripts differ within a yield grade ($P < 0.05$)
The frequency of severe bruising for all the carcasses in every position is 0.0509 (5.09 %)

4.5 DISCUSSION

Carefully controlled studies and commercial studies complement each other in furthering our understanding of cattle transport because one provides insight into commercial conditions and the other provides specific evidence of a particular relationship under explicit conditions (Broom 2014; Goldhawk et al. 2014a). The current study provides a wealth of information regarding commercial transport; it includes both extensive descriptive statistics and an analysis of how particular factors affect outcomes. However, many of these relationships could use further examination by controlling variation in journey lengths, drivers, roads, climatic conditions, cattle management prior to transport and the number of replicates within treatments.

4.5.1 Inter-observer training

The inter-observer reliability in this study for loading, unloading and BCS were relatively high (r = 0.81, 0.83, 0.84; Kappa = 0.75, 0.77, 0.57 respectively). A commonly used scale for Kappa values indicate that results between 0.61 and 0.8 have “substantial” agreement, between 0.41 and 0.6 are “moderate” in agreement and between 0.21 and 0.4 are “fair” in agreement (Viera et al. 2005). Inter-observer agreement for the number of bruises per carcass and the bruising severity per carcass in the current study were all in the “substantial” agreement category and were higher than comparable values reported by Strappini et al. (2012). The inter-observer reliability for bruise score 3 on whole carcasses was comparable to the results of Strappini et al. (2012). Kappa scores in that study for bruise size were between 0.43 and 0.56, whereas Kappa scores in the current study for bruise score 3 were slightly higher, ranging from 0.55 to 0.62 and were in the “moderate” or “substantial” agreement categories.

The inter-observer reliability of bruise score 3 for individual positions were in the "moderate" to "substantial" agreement categories except for the R and BP carcass positions which had only "fair" agreement. In comparison, Strappini et al. (2012) reported "slight" to "fair" agreement for the number of bruises scored on each position of a carcass. It follows that the bruising scores determined by the observers in the current study are acceptable in all the positions except the R and BP. These two positions, although dissimilar, were still within the expected agreement when compared to other studies measuring bruising on individual carcass positions. The percent agreement remained high for all the positions (95.30% to 99.16%) because of the large portion of carcass positions with zero bruising.

4.5.2 Descriptive statistics

Journey Duration

Journey durations can vary dramatically throughout Canada. Mean journey durations have been reported at 19 h for feeder cattle in eastern Canada (Thrower 2009), 5 h for finished cattle in eastern Canada (Warren et al. 2010a) and 16 h for finished cattle in western Canada (González et al. 2012c). The maximum journey duration reported in each of those studies was 120 h, 68 h and 45 h, respectively. Comparatively, the maximum journey duration in the current study was relatively short (7 h 35 min) and could explain the relatively high carcass quality and good welfare of the cattle observed in the current study.

Intuitively, one might expect that increased journey duration may impact animal outcomes. However, it has also been suggested that periods when the trailer is stationary can be even more detrimental to cattle welfare than overall journey length. During stationary periods the passive ventilation that cattle trailers usually rely on is low and temperature and humidity will increase beyond the ambient conditions (Bryan 2013). One of the main stationary periods in the current study occurred during the waiting period. In the study by Warren et al. (2010) cattle waited on average 25 min to unload, although many did not wait at all and others waited for over an hour. Similar waiting times were observed in the current study; cattle waited on average of 26 min to unload and wait times ranged from 1 min to 84 min. Trailers were unloaded within an hour at the slaughter plant, which was the maximum time targeted by the slaughter plant for unloading (Personal communication 2013, yard manager at the federal processing plant). On long distance loads (> 300 km) there were also 10 stationary periods due to traffic, stopping for lunch, or unknown reasons that ranged in duration from 11 to 51 min. These stationary periods that occurred on long journeys likely affected the microclimate and acceleration experienced by cattle while standing in the trailer. These results indicate that it is more likely for stationary periods to occur during a long journeys and drivers should be cautious that these stationary periods do not become too extended because of the link between stationary time and poor animal outcomes.

Handling and (Un) loading scores

It has been suggested that the most stressful part of transport can be the loading and unloading, rather than the actual journey on the trailer (Booth-McLean et al. 2007) and therefore, a number of (un)loading and handling parameters were measured. According to the scoring system described by María et al. (2004), all of the trailers in this study were loaded within the fastest time score (T), indicating that the loading methods used in western Canada are somewhat faster than in Europe where the scoring method was created (less than a min per animal at loading and less than 0.5 min at unloading). Goldhawk et al. (2014d) recorded similar results with cull cows and suggested that the scoring system be adapted to fit western Canadian (un)loading methods and speeds. Therefore, these (un)loading scores could not be used in analysis.

The other half of the scoring system described by María et al. (2004) includes a number of animal or handling activities including: cattle slipping, tripping, falling, mounting, displaying aggression, balking, or being prodded (see Table 4.2 for a more thorough description). The resulting scores during loading ranged from 1 to 5 and at unloading ranged from 1 to 2. Only 20.13% had the best score during loading, whereas 84.34% had the best score during unloading. The loads scored higher during unloading because less cattle activity was observed with one exception; more animals fell during unloading (0.52% at unloading and 0.13% at loading). It is likely that animals fell more at unloading even though the unloading ramp at the slaughter plant had raised ridges on the ground to prevent slipping and shavings for better footing, because they unloaded at a faster speed than they loaded. Scores, using the scoring system described by María et al. (2004), were not significantly associated with any of the outcomes in this study, likely because there was very little variation in scores.

In addition to the scoring system by María et al. (2004), the American Meat Institute (AMI) developed an (un)loading score that included falling. At loading, 33 loads scored ‘excellent’ for AMI criteria 4 (falling). There were 0.13 % of cattle that fell during loading, which caused three loads to transition into the ‘not acceptable’ score. During unloading more animals fell (22.22%) causing eight loads to be in the ‘not acceptable’ category, likely because animals unloaded more quickly and were therefore more likely to fall.

The scoring system described by Warren et al. (2010a), characterized the speed at which cattle exit or enter the trailer and was designed to be an indicator of the temperament of the animals. In the current study, most animals walked onto the trailer at loading (92.17%) and trotted off the trailer at unloading (66.69%). Trotting off of the trailer at unloading, rather than an indication of a negative experience or temperament, was likely a result of the downward slope of the ramps and that cattle are naturally more compelled to get off the trailer because of the exit being lighter and more open (Grandin 2014). The (un)loading speed as described by Warren et al. (2010a) had no association with shrink or bruising in the final multivariable models, however when analyzed individually a trend was noted between unloading speed and bruising (P = 0.063). Perhaps it is more common for animals that move quickly to fall or hit equipment resulting in greater bruising, although this relationship needs further investigation.

No loads in the current study reached the most desirable handling score of 3, as defined by Warren et al. (2010). During loading 61.11% of cattle were in the lowest handling score due to handlers yelling, banging on the trailer, hitting the animals or using electric prods. Whereas, at unloading, handlers were more likely to open the trailer door and leave the cattle to unload and therefore only 25% had the lowest handling score. Nevertheless, no loads were in the most desirable handling score at unloading because it was uncommon for drivers to use the side rail on the ramp when unloading the upper compartments, which is one of the criteria for a desirable handling score, according to Warren et al. (2010a). Although the use of the side-rail at unloading is recommended, in reality few drivers use it at unloading and observers did not see any negative effects of not using it during the current study.

Cattle welfare experts consider the use of electric prods unnecessary except in emergency situations and have found that a reduction in their use can improve carcass quality and reduce stress in livestock (Grandin 2014). There is an opportunity for some cattle handlers to improve their loading techniques by reducing the use of the electric prod, which was used on 19.78% of the cattle in this study. While observing the loading of 36 trailers it was noted that some handlers use the electric prod habitually, rather than for a particular reason, this was especially true in the four loads that had more than 50% of the cattle prodded. This habitual prodding caused those four loads to be categorized as a 'severe problem' in the AMI criteria 5 scoring system (Table 4.5). If these four handlers were to stop relying on the electric prod, the portion of cattle prodded during loading could be dramatically reduced. On the other hand, few animals were prodded prior to slaughter (1.37%) and none were prodded during unloading because of plant policy restrictions.

Cattle condition

The 2010/11 National Beef Quality Audit in Canada (NBQA 2013) reported an $8.17/head cost associated with cattle dirtiness (commonly known as tag) caused by contamination of the carcass resulting in trim loss, and labor costs associated with removal, and processing of the tag-covered hide. On the processing floor, this cost was second only to the cost associated with liver discounts ($9.36/head) and was substantially higher than the costs associated with bruising ($2.10/head). Because of the cost associated with dirty cattle and its indications for poor cattle welfare during transport, the cleanliness of the cattle pre and post transport were recorded during this study. Although only23.29% of cattle were considered dirty in the current study, the NBQA (2013) audit reported that 89.7% of finished cattle in winter were reported to have tag to some degree. The later value is considered unusually high and was a result of an extremely wet auditing year. It could be expected that animals travelling in a trailer would become dirtier during the trip, and although there were a number of animals that had fresh manure on them (especially those cattle in the lower compartments), the overall dirtiness of the cattle decreased by 4.15% from the loading to unloading. This is presumably because cattle rubbed tag off of themselves on the walls of the trailer to below the level considered extremely dirty. This would indicate that finished cattle are not especially prone to getting dirty during the relatively short duration transport as experienced in the current study.

There was also an increase in the number of wet animals by 3.61% at unloading. However, it is difficult to discern whether the animals that were wet at loading were the same animals that were wet at unloading. It was noted by observers that animals were often wet on their backs at loading due to snow or sleet but were wet on their sides at unloading presumably because of sweating. During the waiting time prior to unloading heat and humidity can accumulate in the trailer and it was suspected that a longer wait time would cause more wet animals at unloading. However, there was no relationship between wait time and the number of wet animals at unloading. Likely the number of wet animals is due to an accumulation of factors including; the animals' previous adaptation to cold temperatures, the ambient temperature on the day of transport and the period of wait time. These relationships were not tested in this study but are suggested as areas for further study.

American Meat Institute has developed a scoring system to monitor changes in animal condition during the journey(die during transport, become non-ambulatory or are fatigued). In the current study, one animal was reported as fatigued which caused one load to be dropped out of the ‘excellent’ score for AMI criteria 6. In comparison, the study by Goldhawk et al. (2014c) followed approximately half as many loads of cull cows and reported seven loads that had to be dropped from the ‘excellent’ AMI criteria 6 score for similar reasons. This suggests that finished cattle had good welfare during these journeys because of the relatively low proportion of compromised finished cattle compared with the proportion of compromised cull cows found by Goldhawk et al. (2014c).

Although few animals were compromised during the journey, the number of lame animals observed in the study did increase by 1.46% between loading and unloading, however this score should be interpreted cautiously. Lameness was not used in any model analysis because the scoring method at (un)loading was not conducive to accurate lameness scoring. The visibility of each animal’s gait was often obscured or difficult to judge because of variable handling systems, inconsistent footing and the cattle creating steam during loading, which further reduced visibility. It is suggested that lameness scoring is best accomplished by watching an animal’s movement in its home pen if it is relatively flat because the type of surface can affect an animals lameness. For example, animals will move differently on concrete, gravel, grass or frozen mud (Desrochers et al. 2001). Also, cattle tend to mask signs of lameness when stressed or frightened as a natural method to prevent them from being singled out by a predator (Grandin 2014), which could also have been the case during loading in the current study.

Although it was difficult to characterize the effect that transport had on lameness it was clear that some lameness was present in the finished cattle transported during this study (0.34 – 1.8% of animals were scored as lame). These rates are much higher than the 0.022% observed in a previous Canadian study (González et al. 2012c). Conceivably, this is because the number of lame animals reported by the González et al. (2012c) study was assessed by surveying transporters, whom likely don't have the time or training to accurately characterize cases of minor lameness. Lameness is, nonetheless, a growing concern for feedlot cattle (Paetsch 2014) and should therefore be considered in more detail during future transport studies. Further, lameness has an influence on cattle's ability to maintain balance and remain standing during transport, which can affect their subsequent welfare (González et al. 2012c).

Space Allowance

In the present study the k-values reported for finished cattle being transported ranged from 0.015 to 0.049. In comparison, González et al. (2012c) had k-values that ranged from 0.0109 to 0.157 based on all types of cattle (calves, feeders, cull cows and finished cattle). It is obvious from the distinctive range in k-values that finished cattle are loaded at a more consistent stocking density than other types of cattle. Similarly, both the present study and the study by González et al. (2012c) study reported compartments loaded both above and below the recommended space allowance. The effect of loading density on animal outcomes will be discussed later in this manuscript.

Microclimate

Western Canada is notorious for its extremely cold and unpredictable winter conditions, as observed in the current study with minimum temperatures of -32.35 °C and maximum humidity's of 11.53 g water/kg dry air, resulting in a minimum THI of - 54.2. Cattle, although well suited for quite cold temperatures, are especially susceptible to cold stress when high humidity and air movement reduce the insulative qualities of their hair coat (Monteith et al.

1974). Cattle also increase their moisture production after periods of activity, like during loading (Mitchel et al. 2008). It is logical, therefore, that the highest humidity in the trailers was often noted right after loading (which was confirmed when observing plots of HR over time) or when the passive ventilation from the moving trailer was reduced during stationary periods (Figure 4.14, 4.15, 4.16). When cattle are exposed to low temperatures, high humidity and air movement during transport it is more likely that they will experience cold stress even though they are well adapted to cold weather. However, none of the animal outcomes measured in this study were negatively affected by cold and physiological indicators of cold stress were not measured. Nevertheless, it is important for drivers to be aware that cattle are most vulnerable to cold stress when they are wet and the airflow is highest (COPB 2013). Therefore, drivers should take actions to prevent the accumulation of moisture in the trailer that may cause the cattle to become wet, such as reducing stationary periods, especially when the cattle first enter the trailer.

It would be intuitive to assume that in Canadian cold weather conditions, strategies should be taken to prevent cold stress in finished cattle during transport such as providing protection from the wind and moisture. However, there was no indication of cold negatively affecting cattle outcomes in this study. In fact, there were occasions during this study where increases in trailer temperature and humidity negatively affected cattle outcomes. Gonyou et al. (1979) had a similar conclusion when studying the effects on cold weather and acclimation on the behaviour of feedlot cattle. As the winter progressed during their study, cattle shivered less at colder temperatures (-30 °C) and had lower respiratory frequencies ($P < 0.01$). They also concluded that heat stress was experienced by the cold-acclimated animals when exposed to warmer temperatures (20 °C). Cattle become acclimatized to colder environments by growing a thicker hair coat, increasing their resting metabolic rate, and decreasing the blood flow near the surface (Gonyou et al. 1979). It follows, that finished cattle are quite robust, especially when acclimated to cold weather, and that increased temperature and humidity inside the trailer should be avoided, even in winter conditions. Western Canada is known for its extreme fluctuations in temperature, so cattle transporters should be especially cautious of cattle experiencing heat stress when ambient conditions are warmer than usual (above freezing) especially at the end of winter. The finished cattle, being acclimated to extreme cold conditions and having fat and hair coat for insulation, could be detrimentally affected in these conditions, especially in a trailer where they are unable to express heat-reducing behaviours. Avoiding stationary periods, parking where wind can provide passive ventilation, and not overstocking the trailer could help moderate some of these effects.

Acceleration

Another important factor determining the overall tolerability of a transport experience is the acceleration experienced by the cattle during the journey. Generally speaking, lower accelerations result in a more comfortable journey for both humans and livestock. During this study mean rms of acceleration on the trailers transporting finished cattle in this study were 0.76 ± 0.5 m/s^2, 1.13 ± 0.53 m/s^2, 0.92 ± 0.69 m/s^2 in the vertical, horizontal and lateral axes, respectively (Table 4.3). These results are similar to the preliminary results reported in Manuscript I of this thesis: 1.01 ± 0.32 m/s^2, 0.72 ± 0.31 m/s^2 , 0.97 ± 0.30 m/s^2 in the vertical, horizontal and lateral axes respectively. Any differences in the means are lower than the ± 0.5 m/s^2 change that is generally considered biologically significant (Randall 1992). These values are also comparable to values reported by Gebresenbet et al. (2011), whom measured acceleration on the frame of a European livestock trailer on three road types at four different speeds and calculated mean rms values of 1.52 ± 0.45 m/s^2, 1.32 ± 0.37 m/s^2, 0.81 ± 0.12 m/s^2 in the vertical, horizontal and lateral directions, respectively. However, the vertical axis has a lower mean rms of acceleration by 0.76 m/s^2, which could be due to differences in suspension or other trailer properties between the types of trailers studied. A US study reported lateral accelerations of 0.69 to 2.74 m/s^2 when driving a loaded tractor-trailer through a slalom maneuvering on gravel roads at speeds of 18.5 - 34.8 km/h (Clark et al. 1999). These values were likely higher than in the current study because they travelled on gravel roads while continually turning, whereas, in the current study, the majority of travel was on straight paved highways. Cann et al. (2004) reported a range of acceleration of 0.12 to 0.52 m/s^2 rms on highway transport truck drivers, which was lower than the current study possibly because of the driver's seat mitigating accelerations. The impact of acceleration in has been observed in humans during transport has been described as being a little uncomfortable, fairly uncomfortable or uncomfortable (Randall 1992). The accelerations experienced by the cattle in the current study were above the mean rms of acceleration measured on the drivers of cattle trailers (Cann et a. 2004). It follows that cattle may also find the level of acceleration observed in the current study uncomfortable, especially after long journeys. However it is difficult to compare the human experience to an animals experience because of differences between humans and animals such as bio-dynamics and standing orientations.

Further, the maximum peak rms of acceleration calculated in the current study were substantially higher than from preliminary results found in Manuscript I. The maximum rms of acceleration in vertical, lateral and horizontal directions were above the level (2 m/s^2) at which humans report being extremely uncomfortable (Randall 1992) and above the level (3 m/s^2) at which pig welfare is considered compromised (Perremans et al. 1998). Possibly this is because the rms accelerations in this study were determined for each speed category and compartment whereas, for manuscript I they were averaged by compartment. The highest rms acceleration measured was in the vertical axis in the back while the trailer was stationary, likely this high acceleration was due to cattle moving within the compartment while the trailer was stopped. These high accelerations indicate that there are times during the journey when the cattle are experiencing levels of acceleration that may not be comfortable.

Shrink

Shrink is undesirable as cattle weigh less on arrival, which affects the financial returns to the producer, but also because it is associated with feedlot illness in feeder animals and lower meat quality and quantity in finished cattle (Jones et al. 1990). González et al. (2012c) reported average shrink of 5.3% and as high as 21.8% of body weight. Further, they observed that animals were more likely to become lame (P = 0.09) and non-ambulatory (P < 0.001) when they also had a shrink above 8%. When animals had a shrink of more than 10% they found that it was more probable for animals to become lame, non-ambulatory and die. The average shrink in the current study was much lower (2.14% of body weight) and the maximum shrink was only 3.88%. Possible explanations for the low shrink reported in the current study are the time of day of loading, morning having lower associated shrink (González et al. 2012b), and the relatively short journey durations (< 7 h 34 min) compared to the maximum transport time found in other North American studies: 39 h (González et al. 2012b) and 68 h (Warren et al. 2010a). Cattle in this study were loaded on average at 08:52 ± 1:36 and between the h of 06:30 and 12:11.

Although a large shrink loss was not observed in the current study, it remains that it is not a desirable outcome and that it is important to identify and mitigate key factors that influence the shrink in finished cattle.

BCS and carcass characteristics

The BCS and hot carcass weights of cattle in the present study were similar to those reported in the 2010/11 National Beef Quality Audit in Canada (NBQA 2013), which indicated that 99% of fed cattle in winter had a BCS between 4 and 5 (out of a possible score of 5) and average hot carcass weights were 383.74 kg for steers and 352.89 kg for heifers. The NBQA (2013) reported lower quality grades than the present study: Prime (1.2%), AAA (52.5%), AA (43.4%), and A (2.8%). During the NBQA (2013) audit, they noted that the quality grades were better during winter as opposed to summer; a finding that is consistent with the present winter study which reported a higher proportion of animals in the more desirable quality grades Prime (3.43 %), AAA (70.53%), AA (25.31%) and A (0%).

The fraction of dark cutting animals (quality grade B4) was considerably lower in the current study (0.53%) compared to the portion reported in NBQA (2013) which was 1.28% and the percentage reported by Warren et al. (2010b) which was 2.0%. Possible explanations for the lower dark cutting percent in this study are relatively short journey durations (< 7 h 34 min), the type of cattle (only finished heifers and steers), origin of the animals (feedlot vs. auction markets) and the handling techniques used (Tarrant et al. 1992; Fisher et al. 2009; Warren et al. 2010b).

Although dark cutting is also an important carcass quality defect causing financial losses it was not used as a dependent variable in a final model because of its low prevalence in the current study. If we were to analyze dark cutting as Warren et al. (2010b) did, then any load with over 2% dark cutting would be considered a dark cutting load and be compared to loads with less than 2%. Doing a binary analysis by load rather than by compartment would substantially reduce the n in the study and make it difficult to compare all the possible influencing factors affecting dark cutting cattle.

Bruising in cattle is of increasing concern because of its welfare implications, associated economic loss due to trim of approximately $2.10/head/year and the 62% increase in prevalence of bruising between 1999 and 2011 in Canadian cattle (NBQA 2013). In the current study, the proportion of carcasses with at least one bruise was 85.7%, which was consistent with an incidence of 84.4% on cull cows recorded by Goldhawk et al. (2014c) and 71.2% on cull cows recorded by Strappini et al. (2013) but is considerably higher than other reported bruising frequencies. For example, the percent of carcasses bruised in the NQBA (2013) was 34% and in a Colombian study was 37.5% (Romero et al. 2013). However, in the current study only 24.49% of the total carcass positions were bruised (Figure 4.7), which indicates that although more animals had at least one bruise the bruising did not cover a significant part of their body. Further, the mean bruises per carcass were 1.18, which is lower than the 2.71 bruises per carcass reported by Romero et al. (2013) and the 4.52 reported in the first Manuscript of this thesis on cull cows. These results indicate that most of the cattle in the current study had approximately one bruise and the bruises they did have did not cover a sizeable area of the carcass.

It was not determined how much trim was associated with each of the size scores given to bruises in the current study but the NQBA (2013) stated that of the total bruises they scored 72.3% were 'minor' (0.30 kg of trim), 23.9% were 'major' (0.68 kg of trim) and 3.8% were 'critical' (1.45 kg of trim). In the present study, 64.49% were size score 1, 24.50% were size score 2 and 20.78% were size score 3 (severe bruises; Figure 4.7). The current study had a higher proportion of severe bruises than the NBQA (2013) and higher than the 7% reported in the study by Romero et al. (2013). However, the scale of measurement differed in Romero et al. (2013) as severe was > 16 cm whereas a bruise in the current study was considered severe at > 12 cm. Therefore, the criteria used by Romero et al. (2013) would likely have underestimated the number of severe bruises observed in the current study. Further, it was not possible to determine how many kg of trim were associated with the bruises in the current study so it is also possible that the most severe bruising score in this study included the 'major' and 'critical' trim loss categories measured by the NQBA (2013). Although it would be difficult to determine exactly how much trim was lost due to the bruising in the current study, management strategies that minimize loss are beneficial to the industry..

4.5.3 Microclimate models

Cattle can be detrimentally affected by extreme climatic conditions inside the trailer (microclimate), especially if transported for extended periods of time (Mitchel et al. 2008). The effects of extreme microclimate conditions have been studied extensively in warm, humid conditions and include increases in shrink (Greer et al. 2011; Bryan 2013), lame, non-ambulatory, and dead cattle (González et al. 2012c). The effect of cold climates has been studied less extensively but midpoint ambient temperatures below -15 °C and temperature ranges greater than 40 °C have been associated with more deaths in cattle (Mitchel et al. 2008; González et al. 2012c). Lack of research in cold climates may be because extreme cold conditions occur less broadly than extreme hot conditions in the major beef producing nations, such as Australia, Europe, South America and the southern US) and further, cattle are more tolerant of cold than hot conditions (COPB 2013).

The microclimate inside a trailer can be highly variable and dependent on a number of factors. In the present study it was determined that a combination of journey duration, compartment in the trailer, and ambient temperature had an affect on the ΔTemp, ΔHR and ΔTHI. In other studies a number of other factors have been found to affect the microclimate in the trailer. Goldhawk et al. (2014c) found that ambient temperature and vehicle speed also affected internal temperatures ($P < 0.01$) when calves were transported. Goldhawk et al. (2014c) also noted that as temperatures became colder, the ΔTemp, ΔHR and ΔTHI increased and although they attributed these to side ventilation openings being covered, which were not used in the current study. However, due to the large size of the finished cattle, they could be increasing moisture and temperature within the trailer, themselves, or blocking airflow through the trailer. Cattle also produce more heat and moisture after periods of activity such as after loading (Mitchel et al. 2008). Further, heat and moisture accumulate more quickly when the vehicle is stationary, when the cattle are closely packed or when ventilation is reduced (Mitchel et al. 2008).

In the current study, there was a three way interactive relationship between journey duration, trailer compartment and ambient conditions (Figure 4.7 to 4.12). This is contrary to that observed by Greer et al. (2001) who reported no change in ΔTemp between long (900 km) and short (100 km) journeys. The effect of journey duration in the current study could also have been due to the presence of stationary periods ranging from 11 to 51 min in ten out of the fifteen long-distance loads , which did not occur on short distance loads. Stationary periods have reduced passive ventilation in the trailer causing fluctuations in internal trailer conditions (Bryan 2013). Another explanation is that longer journeys provide more time for cattle to relax and reduce their heat and moisture production and longer for the ventilation provided by the movement of the trailer to dissipate the heat and moisture that can quickly accumulate at the beginning of a journey (Mitchel et al. 2008).

Greater ΔTemp, ΔHR and ΔTHI were found during the steady state (last 30 min) in the bottom three compartments (nose, belly and back) of the trailer. Similarly Bryan (2013) also reported greater Δ relative humidity in the bottom vs. top compartments ($P < 0.001$). Conceivably, this could be due to the accumulation of liquid manure in the bottom compartments as steam from the warm manure could be adding to the difference between internal microclimate and external conditions. However, this explanation is purely speculation. Although bottom compartments had on average the greater ΔTemp the top compartments (deck and doghouse) had the highest peak temperatures, possibly because they are most susceptible to radiant heat from the sun.

At low ambient temperatures, HR, and THI the nose compartment had consistently high ΔTemp, ΔHR and ΔTHI. A possible explanation for the observed increase is that the tractor blocks the airflow in the nose compartment causing less air exchange between internal microclimate and ambient conditions (Bryan 2013). This theory was proposed by Bryan (2013), whom also found the nose had greatest mean temperature and change in temperature from ambient during stationary events. Another factor is that the nose compartment receives the least passive ventilation from the wind while driving because the tractor causes an area of low pressure at the front of the trailer, the pressure increases toward the mid to back of the trailer causing the air to flow into the back of the trailer and forward from the point of entry (Mitchel et al. 2008).

The stationary period prior to unloading the cattle at the slaughter facility is especially prone to increases in trailer temperature and humidity (Bryan 2013). This is because, as previously mentioned, cattle trailers rely on passive ventilation to exchange any accumulated heat or moisture in the trailer (Mitchel et al. 2008). Further, when the trailers are parked at the slaughter facility they are not only stationary but also parked side by side, which blocks ventilation that would have been provided by the wind. A positive quadratic relationship, dependent on the compartment in question, was found between wait time and ΔTemp, ΔHR and ΔTHI ($P < 0.0001$).

It should also be noted that microclimate conditions were recorded by sensors on the ceiling of the trailer rather than at animal height. A difference between animal height temperatures and ceiling height temperatures has been recognized but when measured the difference is small 1.18 °C indicated by Greer et al. (2011) and 2.23 – 3.38 °C indicated by Bryan (2013).

4.5.4 Acceleration model

The acceleration (movement) measured in this study reflected both the vibrations of the trailer and the whole-trailer movements, for example when the trailer brakes or drives over a bump. These accelerations can be affected by a number of factors including: vehicle suspension, truck speed, road surface conditions, the movement of the animals, the direction of the vibration, the driver or the driving style (Peeters et al. 2008; Gebresenbet et al. 2011). Not only do the accelerations on the trailer change but the actual accelerations experienced by the animal can be influenced by the animal's orientation, body size and position within the trailer (Randall 1992). Gebresenbet et al. (2011) confirmed the positive relationship between acceleration and speed of a trailer in the vertical axis ($r^2 = 0.92$). In the current study, this relationship was seen most prominently in the horizontal axis in the nose compartment and in the vertical axis on short journey durations. This relationship, however, is being superseded by other factors in some circumstances. The lateral axis, for example, was not significantly affected by the speed of the trailer at all. In some compartments the acceleration was actually highest when the trailer was travelling at slow speeds (< 10 km) or stationary. This was the case when horizontal acceleration was measured in the back during long journeys and when vertical acceleration was measured in the back compartment at both journey durations. Tarrant (1990) discussed the association between increased movement of cattle (due to loss of balance) during cornering and braking which were most likely to occur in the current study when trailers were driving slowly, especially when passing through towns. Therefore, a possible explanation for increased acceleration during slow trailer movement is the increased whole-trailer acceleration (due to stopping and starting) and cattle themselves causing increased vibrations on the floor of the trailer (due to more moving around and loss of balance).

The greatest acceleration in the lateral direction was in the doghouse compartment on long journey durations followed by the nose compartment. Cattle in the doghouse and nose compartments were often loaded at comparatively low space allowances and therefore have the most room for cattle to move around creating vibrations on the floor of the compartment. Further, on long journeys cattle would have the most time to become accustomed to being on a trailer and be more likely to move around. Another possible explanation is that the driving style or route of the drivers on the longer journeys could have influenced the lateral movement of the trailer especially in the doghouse compartment because of its height above the ground and orientation above the rear tires.

4.5.5 Shrink model

There were four variables that significantly affected shrink in the current study. As expected, the shrink increased with longer journey durations ($P < 0.001$) however the change was small (approximately 1%). Greer et al (2011) also found that journey distance affected carcass grades, with fewer animals graded AAA ($P = 0.02$). Similarly, González et al. (2012a) also found that time on truck had a positive relationship with shrink ($P < 0.001$). The distance from the feedlot to the nearest slaughter facility can not be controlled by the feedlot operator or transporter, nevertheless, to reduce the shrink-loss, the shortest path, with minimal stops, should be used to reach the slaughter plant.

Although internal temperature in the current study reached as low as -32.35 °C, it is possible that the cattle experienced very little cold stress. The finished cattle in this study were acclimated to cold winter conditions with high rates of metabolic heat production, thick hair coats and lots of fat cover providing insulation (Houseal et al. 1995; Mitchel et al. 2008; Bryan 2013). In fact, it is possible that some of the cattle experienced heat stress because trailer conditions increased well above ambient conditions in some cases. This is especially true during the stationary waiting period prior to unloading when internal trailer temperatures rose up to 15

°C above ambient , the humidity ratio rose up to 6 g water/kg dry air above ambient and THI rose up to 20 °C above ambient. The theory is supported by the results found in the current study that indicate that mean THI has a positive relationship with shrink during cold weather conditions ($P < 0.001$), suggesting that shrink increased as the mean THI increased. Similarly, Greer et al. (2011) described mean trailer THI to be positively associated ($P < 0.0001$) with finished cattle shrink during warm weather conditions (23.99 ± 0.05 °C) and González et al. (2012a) reported midpoint ambient temperatures with a positive relationship with shrink throughout all seasons ($P < 0.001$).

Shrink is also positively associated with the maximum allometric coefficient (k) in the current study ($P < 0.001$). In another study, shrink was greater in the nose compartment (3.50 ± 0.19%; $P = 0.0015$) and the least in the back (2.69 ± 0.18%) during summer transport of finished heifers (Greer et al. 2011). It has also been determined that animal death can increase at very low k-values (k =0.015; $P = 0.007$) and at very high k-values (k = 0.035; $P < 0.001$) depending on the compartment within the trailer (González et al. 2012c). In the present study, the analysis of k-values was accomplished on entire loads, so compartments could not be compared. However, it is apparent from the descriptive statistics that the nose and doghouse compartments are often loaded at a greater k-value than the other compartments. So, it follows that overall shrink was likely increased by loads with greater k-value, because of a low stocking density in the nose or doghouse compartment. Possibly greater maximum k-value causes increased shrink in cattle because of the stress of being separated from their companions and more room for them to partake in restless behaviours. No relationship between low k-values and shrink were determined in the current study.

Unexpectedly, shrink decreased with increasing prod use ($P = 0.0012$), which is contrary to indications from other studies discussed below. The explanation for this association is unclear and no other studies can be found to corroborate the finding. Conceivably, cattle in this study could have been prodded more at loading because they were slower and also had a calmer temperament. The calmer temperament then reduced the stress the cattle experienced during travel and consequently those cattle shrank less. That is unlikely though because handlers that prodded the most usually did it habitually and not based on animal temperament. When scoring the prodding, observers recorded every time the prod contacted the animal but it was not possible to tell if the handler had actually electrified the prod. Possibly, the highest rates of prodding were not actually as stressful as initially assumed because the prod was not electrified for many of the cattle. It is important to note that the findings regarding prodding use observed in the current study This are contrary to the common logic that electric prodding causes stress (Grandin 2014) and that stress increases shrink (Jones et al. 1990).

4.5.6 Bruising model

The rupture of vascular blood supply and the consequent accumulation of blood in tissues forms bruises. They are caused by the application of a force on the tissue of cattle, for example from cattle hitting equipment or from handlers hitting the cattle (Nanni Costa et al. 2006). Therefore, bruises can indicate unfavorable welfare conditions (Strappini et al. 2012). The analysis of severe bruising (bruise score 3) in the current study was designed to examine the impact of transport variables on the incidence of bruising. The goal of the study was to determine which of the variables that affect bruising can be managed so that severe bruising can be decreased and, subsequently, animal welfare increased.

Many transport variables were individually analyzed with bruise score 3 but only 5 remained in the final multivariable model: yield grade, position on carcass, beta-agonist use; x-axis acceleration and total wait time. A two-way interaction of yield grade and carcass position was found to have significant (*P* = 0.0025) impact on the number of severe bruises. Yield grade alone didn't have a significant effect but did when specific carcass positions were studied. The back anterior (OR = 23.94) and back posterior (OR = 16.48) had the highest likelihood of having severe bruising in cattle with Yield 1. Whereas, the left loin and right loin had the highest likelihood of severe bruising in cattle with Yield of 2 (OR = 4.08 and OR = 5.28 respectively) or 3 (OR = 2.62 and 3.78), respectively. The round position on the carcass consistently had the lowest likelihood of severe bruising and was therefore used as the reference for odds ratio calculations of the yield and position interaction (Table 4.12).

The lean meat yield is calculated using rib-eye length, rib-eye width and fat depth on the rib-eye. A yield grade of 1 has 59% or more lean meat, a yield grade of 2 has 54-58% lean meat and values less than 53% are classified as a 3 (Canada Beef Inc. 2012). This means that an animal that has a yield grade Y1 is leaner than an animal that has a yield grade Y3. The yield distribution in Canadian cattle reported by the 2010/11 National Beef Quality Audit (NBQA 2013) was: Y1 = 52.4%, Y2 = 33.5% and Y3 = 14.2%. The current study concluded that it is likely for leaner cattle to have severe bruising along their back and fatter cattle to have bruising along their loins. In this study the round was not a common location for severe bruising in finished cattle. Similarly, Strappini et al. (2010) found that carcasses with lower fat cover were more likely to have a high prevalence of bruising (*P* < 0.0001). A possible explanation for this pattern of severe bruising is that the fat cover protects the back from bruising when animals are

Y3. It could also be a function of the accumulated tissue on the back of the animal causing the bruises on the muscle tissue below to be more difficult to discern.

In the current study total wait time (lairage time + wait time = total wait time) between arrival at the slaughter plant and slaughter had a significant effect on severe bruising (P = 0.0052). Cattle that are transported on longer journeys generally have a longer lairage time, commonly overnight at Canadian federal slaughter plants (Personal communication 2013, yard manager at federal processing facility). During the current study, lairage times were restricted to same-day slaughter, which reduced the lairage times and total wait-times (maximum = 5 h 9 min). In the present study, an hour increase in the total wait time at the slaughter plant resulted in less severe bruising (OR = 0.8; $P < 0.0052$). This is contradictory to conclusions from other studies regarding the relationship between bruising and lairage time or bruising and wait time. Goldhawk et al. (2014d) reported that an increase in waiting time from 60 to 90 min increased the likelihood of severe bruising (OR = 1.18; $P = 0.001$). In a study conducted by Romero et al. (2013) in Colombia they found that lairage times between 18 and 24 h increased the probability of severe bruising by 2.1 times compared with lairage times between 12 and 18 h ($P < 0.01$). The results of these studies indicate that short wait times and lairage times (< 60 min and < 5 h 9 min respectively) decrease the likelihood of severe bruising but when either the lairage time or wait time becomes too long the likelihood of bruising is increased. Possibly there is an ideal total wait time that allows animals to relax for further handling but is not long enough for them to begin engaging in activities that might cause bruising (such as fighting or mounting). In contrast to this theory, a Chilean study by Strappini et al. (2010) concluded that an increase in lairage time from 6 to 24 h decreased the likelihood of bruising (OR = 0.6; P <0.0001). Although the relationship isn't entirely clear, there is obviously an association between total wait time, wait time, lairage time and severe bruising.

To the author's knowledge, the impact of acceleration on bruising in cattle has not been studied previously. Nevertheless, there have been many factors linked to bruising that also affect acceleration, which indicates that bruising and acceleration are indirectly linked, at least. Road conditions can influence ($P < 0.08$) bruising (Huertas et al. 2010) as well as stress indicators in sheep and pigs (Bradshaw et al. 1996; Ruiz-de-la-Torre et al. 2001) and have also been linked to changes in horizontal vibration levels (Gebresenbet et al. 2011) and overall acceleration peaks (Ruiz-de-la-Torre et al. 2001). Greater driver experience has been linked with fewer compromised animals ($P < 0.001$) and increased driver training has been linked with a reduced incidence of dark cutting carcasses ($P = 0.008$) (González et al. 2012c; Warren et al. 2010b). In addition, driving style has also been found to affect lateral and horizontal acceleration (Peeters et al. 2008). Gebresenbet et al. (2011) reported that trailer speed is positively associated with vertical acceleration ($r^2 = 0.92$). Furthermore, Clark et al. (1999) reported increased lateral acceleration of 2.45 m/s^2 and 2.05 m/s^2 when the speed of a U-turn increased from 8 to 40 km/h and when the speed of a slalom maneuver was increased from 18 to 35 km/h, respectively. It was also determined by Tarrant (1990) that cornering at high speeds causes cattle to lose their footing, which they speculated could result in greater bruising. It would follow that increased acceleration, especially in the lateral or horizontal axes, would cause more bruising in cattle. However, only the vertical acceleration was significantly associated with bruising in the current study. A 1 m/s^2 increase in vertical acceleration increased the likelihood of severe bruising in cattle by 1.81 times (OR = 1.81; $P = 0.0054$). Vertical acceleration had the highest maximum rms of acceleration (9.75 m/s^2) and has been linked to muscular fatigue and motion sickness. The inclusion of acceleration measures such as crest factor and vibration dose value in future studies of this type could further reveal the nature of this relationship.

Lastly, it was determined that the relationship between beta agonist (β-adrenergic agonists) use and bruising is such that the likelihood of bruising is decreased when beta agonists are used. The use of beta-agonists in finishing cattle results in increased production parameters such as: average daily gain ($P < 0.01$) gain to feed ratio ($P < 0.01$), hot carcass weight ($P < 0.05$) and hot carcass yield ($P < 0.05$) (Avendaño-Reyes et al. 2006), which is why they are routinely used in feedlot production. To our knowledge, the connection between bruising and beta-agonists has not been reported previously, however, beta-agonists have been connected with increased, rather than decreased carcass quality defects, specifically reduced meat tenderness or color (Avendaño-Reyes et al. 2006; Dikeman 2007). Beta-agonist use has also been associated with increased blood flow and reduced adipose tissue (Yang et al. 1989), which is why it is counter intuitive that the likelihood of severe bruising was decreased with the use of beta-agonists. Further, Baszczak et al. (2006) reported that cattle given beta-agonists entered a chute more rapidly than cattle without, indicating a 'flightier' temperament between animals given beta agonists and those without; also suggesting that the findings in the current study are counterintuitive. There is no clear explanation for the connection between decreased likelihood of severe bruising and beta agonist use and therefore the relationship between there parameters merits further testing before definite conclusions can be drawn.

There are also many other factors, not considered or shown significant in the current study, that have been found to affect bruising, discussed below. There is a commonly reported association between increased bruising and cattle originating from auction marts rather than directly from the farm (Jarvis et al. 1995; Strappini et al. 2010). All of the cattle in the current study were shipped directly from a feedlot and therefore this relationship could not be studied. Romero et al. (2013), a Colombian research team, reported that increased bruising in their study was associated with loading density (both too high and too low) and stops during transport; neither of which were corroborated in the current study. These contradictory results could be attributed to a number of variables including the different style of transport vehicles used in the studies, differences in travel durations or loading densities.

Although, Chilean (Strappini et al. 2012), European (Jarvis et al. 1995) and Uruguan (Huertas et al. 2010) studies have connected the use of driving aids and prods with increased bruising no significant relationship was found in the current study. Slaughter plant regulations restricted the use of prods during unloading therefore the relationship with prodding during unloading was irrelevant in the present study. Nanni-Costa et al. (2006) even compared the individual behavioural events measured in the scores reported by María et al. (2004) to the bruising in bulls. Only the behavioural event balking had a significant relationship with bruising ($P < 0.05$); falls, reversals, heads, mounts, jumps, slips, evacuations, and vocalizations were not associated with increased bruising.

Contrary to the current study, Goldhawk et al. (2014d) found that compartment had an effect on carcass bruising in cull cows, but a space allowance did not. Bruising in cull cows in that study was more likely to occur in the doghouse compartment than in any other compartment (OR = 2.2-3.8; $P < 0.01$). This difference in results could be explained by the difference in cattle type between the two studies. Perhaps cull cows are at higher risk in the doghouse because they are generally less robust than finished cattle and may have more difficulty getting to the compartment, which is the smallest one, on the second floor and around 90° turns (Goldhawk et al. 2014d). It is also possible that the cull cows were taller than finished cattle and more likely to hit the low ceiling when maneuvering.

The main causes of bruises on cull cows in a Chilean study were animal-facility interaction in the stunning box, animal-animal interactions during lairage and human-animal interaction during (un)loading (Strappini et al. 2012). Similarly, a European study recorded potential causes of bruises to be from contact with gates (including guillotine gates) and other structures, use of driving aids or from slipping, falling or being mounted by other cattle during unloading and pre-stunning (Jarvis et al. 1995). It was not possible to definitively know the cause of specific bruises in the current study due to its design, but some general observations were made. The backup gates in the serpentine alley leading up to the stunning box may have caused some bruises on the rump of the cattle, as was also speculated by Jarvis et al (1995). However, it is important to recognize that there were a number of backup gates along the alley but only a few were lowered for use at any given time. It is also possible that when two animals tried to enter or exit the trailer through a single-width trailer door, bruises resulted on the sides of the animals. This did occur during the trial although infrequently. It has also been conjectured that the stunning box is a significant source of bruising (Strappini et al. 2012) however the design of the stunning box in the current study was such that cattle slid onto a chest height conveyer that carried them to the stunning area. It is unlikely that this system caused many bruises because the animals are unable to slip or fall and the vast majority were willingly to enter the stunning box without provocation (98.63%).

The guillotine-style sliding trailer door, similar to the type of door on the trailers in the current study, was reported to be associated ($P < 0.05$) with increased bruising by Huertas et al. (2010). However, they did not record specific events of cattle being hit by the trailer door. Therefore, it is possible that the increased bruising was caused by drivers closing the door on animals backs or leaving the door too low while (un)loading which were uncommon events in the current study (three occurrences during loading). These events were recorded but were included as part of the handling score reported by Warren et al. (2010) handling score, which was not associated with increased bruising in the final multivariable model. However, the unloading score reported by Warren et al. (2010) did tend to increase severe bruising when individually analyzed ($P < 0.063$) but the improper use of the sliding rear door could not have been the cause of this trend.

4.6 CONCLUSION

In this study, we examined the descriptive statistics during commercial transport of finished cattle in Canadian winter conditions. The parameters described included: feedlot management prior to transport, temperature and humidity inside and outside the trailer, acceleration of the trailer, handling and management of the cattle during loading and unloading, the duration of each portion of a journey and the loading density. After transport, shrink, animal condition, carcass quality and bruising were described.

The microclimate of the trailer was affected by the three-way interaction of journey duration, compartment in the trailer and the ambient conditions. Significant increases in temperature and humidity above ambient conditions were associated with the waiting period at the slaughter plant prior to unloading. These results can be used to better understand the internal trailer conditions at specific ambient temperatures in each compartment of the trailer during a winter journey. They can also be used to predict the levels of moisture and heat accumulation in the trailer during stationary periods in winter.

Acceleration measured on the cattle trailers differed depending on the direction of movement (vertical, lateral or horizontal) and was affected by two-way interactions between the speed of the trailer, compartment and journey duration. These results can be used to predict the level of acceleration experienced by finished cattle being transported to slaughter and provide the necessary justification for the cautious driving recommendations that are made in driver training courses. This information also provides a benchmark that can be used in the design of future studies testing the relationship between acceleration and bruising.

This study has highlighted some of the transport variables that can be manipulated to result in reduced bruising and shrink, both of which cause of substantial financial and production losses in the beef industry and are also linked to reduced cattle welfare. Specifically, reducing the use of beta-agonists, reducing the vertical acceleration of the trailer, and ensuring an adequate total wait time, could help reduce the occurrence of severe bruising. Shrink could be reduced by shorter journey durations, lower mean THI, and ensuring the space allowance in the nose and doghouse compartments are not unreasonably high. The reduction of bruising and shrink could result in improved animal welfare as well as profitability of the industry.

Generally speaking, finished cattle are robust and well suited to handle the challenges associated with transport. Cattle type, environmental conditions, driving techniques, (un)loading techniques and handling are important factors influencing the transport experience of cattle and should be considered when transport management decisions are made.

5. GENERAL DISCUSSION

In Canada, the transport of cattle often involves lengthy journey durations (> 42 h), extreme climatic conditions (- 30 °C to + 30 °C) and variable handling and driving techniques (Warren et al. 2010a; González et al. 2012b). In addition, cattle management prior to transport determines how physically and mentally prepared the cattle are for a journey. Studies have determined that the previous handling and management of cattle can either cause them to be easier to handle and less stressed during transport (if the previous experience was positive) or harder to handle and easily stressed during transport (if the previous experiences were negative) (Le Neindre et al. 1996). Studies have also shown that cattle can grow accustomed to travel and therefore be content during a journey (Tarrant 1990). On the other hand, it is widely accepted that there is a multiplicative effect of negative transport conditions, especially when the animal is already in a weakened state prior to transport (Mitchel et al. 2008). Therefore the effect of transport on cattle ranges from neutral to extremely aversive, depending on a combination of factors including the type and state of the animal, the in-transport factors, and the handling of the animals. If any of these factors are not ideal, the animal can experience negative outcomes such as lameness, shrink, dark cutting, and bruising. These outcomes not only indicate poor animal welfare but also indicate a significant economic loss to the industry therefore it is imperative to understand how the factors can be effectively measured, how they influence the cattle, and how they can be adapted to result in the greatest positive impact on the cattle (NBQA 2013).

There were a number of objectives of this thesis; (1) to develop and validate a method of measuring trailer motion (acceleration) in cattle transport trailers, (2) to apply this method to trailers transporting cull cows and finished cattle to determine the impact of motion on cattle welfare and carcass quality (3) to determine pre, post and in-transit descriptive statistics of commercial finished cattle loads in Canadian winter conditions (4) to determine transport variables that affect the acceleration and internal trailer microclimate (5) and to determine the relationship between indicators of animal welfare (bruising and shrink) and transport variables.

One of the factors that have been associated with increased stress and poor welfare in cattle is the motion (acceleration) of the trailer. In fact, many transport-training courses include recommendations for slow stopping and starting as well as careful cornering; even though there is little evidence linking trailer acceleration to cattle bruising, other than anecdotal observations of cattle losing balance (Tarrant 1990; CARC 2001). Additionally, it is difficult to measure acceleration for long time periods with wireless accelerometers. Most accelerometers with the capacity to measure acceleration at a high enough rate (> 200 Hz) are quite expensive (> $1000), wired in, difficult to move onto and off of a trailer, or only sample for very short periods of time (< min). For these reasons, a new methodology was necessary to measure acceleration in commercial transport trailers, as described in Manuscript I of this thesis.

A practical and effective method of fastening accelerometers into commercial transport trailers was also identified in Manuscript I. The accelerometers were bolted to a c-clamp and attached to the floor below each compartment of 8 trailers transporting cull cows. The accelerometers used in this study were relatively inexpensive (< $100 each), could be set to record at > 200 Hz, self contained and recorded acceleration over many hours. Calibration with a wired accelerometer was used to determine the accuracy of the sensors. If the manufacturer, using the experimental attachment methods, has not already calibrated the sensors then this type of calibration is recommended. Although the same methodology could be used successfully in future studies, there are some improvements that could increase the usefulness of the results. Primarily, sensors are now commercially available with improved batteries, which would remove the need for a dead-band setting. The dead-band setting restricted the interpretation of the accelerometer data and therefore the applicability of the results from the current sensors. Further, if a method could be determined to attach the sensors to the top of the floor, or to the cattle themselves rather than the framework of the trailer it would reduce the error associated with the transmission of acceleration through the trailer. The resulting data would more accurately reflect the accelerations actually experienced by the cattle rather than the acceleration of the trailer. That being said, the methodology developed in Manuscript I is effective at measuring trailer acceleration and can be used in future studies comparing animal outcomes to trailer motion.

Although no significant association was found between trailer acceleration and bruising in Manuscript I there was a relationship between vertical (x-axis) acceleration and severe bruising in Manuscript II. The lack of significance found in Manuscript I was not unexpected because of the low number of replications (n = 7). The association of large magnitude vertical acceleration and severe bruising is logical because it could cause loss of balance in cattle, however, lateral (z-axis) and horizontal (y-axis) acceleration were expected to have a more significant relationship with bruising as they have been linked to cattle imbalance and falling during transport (Randall 1992). Possibly this discrepancy was due to the measurements analyzed; the root mean square (rms) of the overall acceleration was used instead of measurements that would better characterize trailer events like harsh braking or fast cornering. These events may result in carcass bruising from animal – animal interactions or animal – trailer interactions. In any case, elevated vertical acceleration should be avoided, in order to reduce severe bruising in finished cattle (P = 0.0054). Vertical acceleration was dependent on the journey duration and speed of the trailer (*P* = 0.0315). Vertical accelerations reached peaks both at the highest and slowest speeds, therefore travelling through areas that would require slowing down and stopping often (such as in towns) and avoid travelling at high speeds (> 90 km/h) on uneven roads should be avoided.

Manuscript II was an in depth study of the factors effecting finished cattle outcomes during Canadian winter conditions. The existing research on cattle transport includes little, if any, information on the effects of cold climates on cattle outcomes, likely because most of the transport research, until recently, has been conducted in Australia, South America or Europe where the climates are not typically as extreme (Tarrant 1990; Malena et al. 2006; Strappini et al. 2010; Polkinghorne et al. 2013) or they were accomplished during summer months in North America (Bryan 2013).

Compared to other types of cattle, finished cattle in the current study were quite robust, in good health, were all sourced from feedlots rather than auction marts and had been previously handled. Consequently, none of the cattle became non-ambulatory or died. Further, the cattle had lower than average shrink (2.14%; NQBA 2013), had smaller than average percentage of dark cutters (0.53%; Warren et al. 2010b), less bruising than that found on cull cows (González et al. 2012c) and only one animal was compromised due to fatigue. Our data suggest that finished cattle in these conditions fare well during transport during typical Canadian commercial transport. The negative aspects of transport would need to be quite severe before finished cattle would experience severe welfare issues such as becoming non-ambulatory or dying during transport. A similar conclusion was drawn by González et al. (2012c) who reported feeders and finished cattle to be less likely to die or become non-ambulatory in-transit than other types of cattle. In comparison to the current study, Goldhawk et al. (2014d) followed 673 market cows during transport; on those loads three cows went down and were euthanized on the truck. Whereas, of the 1552 finished cattle were transported in the current study and only 1 animal became compromised during the journey because of fatigue (a much less severe outcome). There are a number of reasons why finished cattle are less likely to become compromised and these include but are not limited to the following: they are transported direct from farm to slaughter and not typically marketed through auctions, they are loaded at a more consistent density, usually remain with their familiar pen mates, are almost always in good body condition, have mature immune systems, possess large gut storage capacity, have good pre-transport nutrition and are well adapted to Canadian winter conditions (Strappini et al. 2010; González et al. 2012c; Schwartzkopf-Genswein et al. 2012).

Although, finished cattle are less likely to be compromised during transport, the goal of Manuscript II was to monitor as many variables as possible that occur on typical loads of cattle being transported in western Canada and identify strategies to reduce severe carcass bruising and shrink. These variables included the management of the cattle, the handling and (un)loading, the general condition of the cattle, the climate inside and outside the trailer, the motion of the trailer, and the time spent during each portion of the journey and in lairage. The effect of these variables on the shrink and bruising was measured. In addition, the variables affecting the microclimate in the trailer and the motion of the trailer were also studied.

In the microclimate model of Manuscript II, it was determined that the combination of journey duration, compartment within the trailer and ambient climate all affected the internal microclimate. A few specific conclusions were drawn. First, the internal temperatures (-32 to 25

°C), HR (0.21 to 11 g water/kg dry air), and THI (-54 to 26) vary dramatically during western Canadian winter transport. Second, as the ambient conditions get colder and less humid the ΔTemp, ΔTHI and ΔHR increase. Therefore, the colder and drier it is outside the trailer, the warmer and more humid the inside of the trailer will be by comparison. Third, during the last 30 min of a journey the three bottom compartments of the trailer have greater ΔTemp, ΔTHI and ΔHR potentially due to accumulated manure. Fourth, the two top compartments have the highest peak ΔTemp, likely due to radiant heat from the sun. In many circumstances the nose had the highest ΔTemp, ΔTHI and ΔHR, conceivably because of the airflow restrictions in that compartment (Bryan 2013). Differences in microclimate between long and short journeys were attributed to the 10 extra stationary periods that occurred during long but not short journeys. Stationary periods are associated with an accumulation of heat and humidity in the trailer (Mitchel et al. 2008; Bryan 2013). In this study a 60-min stationary period resulted in an increase in temperature between 5 and 11 °C above ambient, an increase in HR of 1.47 to 2.43 g water/kg dry air above ambient, and an increase in THI of 6.49 to 12.13 above ambient. It was determined that the internal microclimate experienced by the cattle changes based on journey duration, differs between the beginning and end of the journey, differs based on ambient conditions and the compartment. If cattle transporters wish to manage the internal trailer conditions they must have unique strategies in each of these situations and locations in the trailer.

The relationship between microclimate and animal outcomes was also measured. Interestingly, shrink increased as the mean THI increased ($P < 0.001$). A similar relationship has been reported during warm seasons (Goldhawk et al. 2014b) but this relationship has not been fully considered during cold seasons. Our results indicate that finished cattle are sensitive to internal THI values higher than what the cattle are acclimated to; in winter when cattle are acclimated to very low temperatures (-10 to -30 °C) it could mean that even a THI above freezing could be too high for cattle comfort. Further, a multiplicative affect between journey duration and ambient temperatures has been reported (González et al. 2012a), however this interaction was not considered in this study because the number of replications (n = 32) did not support the analysis.

It is unrealistic to expect truck drivers to drive continuously without stopping, nonetheless, reducing the amount of stationary time could benefit the cattle by minimizing potential increases in humidity and temperature in the trailer and reducing the overall journey duration. The effect of the journey duration on cattle has been widely studied internationally but has only recently been examined in Canada (González et al. 2012c; Warren et al. 2010b). An extensive survey of cattle movement in Alberta reported that there is a sharp increase in cattle becoming lame, non-ambulatory or dead on board beyond 30 h of travel ($P < 0.001$; González et al. 2012c). The generally accepted relationship between journey duration and shrink loss was substantiated in the current study ($P < 0.001$) because cattle transport on the long journeys (> 300 km) shrank approximately 1% more than those on short journeys (< 300 km). It is well accepted that a longer journey will result in greater shrink because cattle must go long without feed and water (Hogan et al. 2007; González et al. 2012a). Urination and defecation would have been the main source of weight loss in the current study because all the journeys were within the 12-hour timeframe, which is considered the approximate threshold after which tissue shrink begins (Hogan et al. 2007).

Compartment and space allowance are inevitably confounding variables when studying finished cattle transport. This is because the space allowance is considerably more variable in the nose and doghouse compartments than the back, belly and deck compartments (Schwartzkopf-Genswein et al. 2012). Truck drivers are limited in their loading techniques by axle weight restrictions, therefore, cattle stocking density is often manipulated to meet these restrictions (González et al. 2012c). Truck drivers should be cautioned not to load cattle at k-values > 0.035 because of the increased risk of cattle becoming lame, non-ambulatory, or dying (González et al. 2012c). Additionally, shrink increased by 2.56% as the k-value increased from 0.02 to 0.05 ($P < 0.001$) in the current study. Another study also reported more severe bruising in the doghouse (OR = 3; $P < 0.01$), which could be partially attributed to the higher k-values that were experienced in that compartment (Goldhawk et al. 2014d). It follows that an allometric coefficient between 0.02 and 0.027 as suggested by Petherick et al. (2009) is suitable for finished cattle being transported in conditions similar to the present study. This discussion has largely focused on high space allowances because exceptionally low space allowances are not typically reached in finished cattle transport. When loading finished cattle, truck drivers are usually restricted first by the weight of the cattle rather than the amount of available space (Schwartzkopf-Genswein et al. 2012). Whereas calves can be loaded at a much lower space allowance and still be under the trailers weight restrictions causing over-crowding to be a more serious issue in lighter types of cattle. One of the greatest risks associated with inadequate of space allowance is that cattle will fall down and not being able to get up again (Tarrant 1992). In areas the weight restrictions are less limiting, both excessive and insufficient space allowances have been associated with increased carcass bruising in finished cattle (Romero et al. 2013).

Handling, loading and unloading techniques have long been associated with cattle welfare, especially with regards to the use of electric prods (Le Neindre et al. 1996; Grandin 2001; Fisher et al. 2009; AMI 2012). The handling and (un)loading scores measured in the current study were previously connected with physiological indicators of stress (María et al. 2004) and dark cutting (Warren et al. 2010b) but were not associated with shrink or carcass bruising in the current study. Unexpectedly, an increase in shrink was found when cattle were prodded less during loading ($P < 0.0012$). It would have been more logical if increased prodding had caused more shrink because of the connection between shrink and stress (Jones et al. 1990; Grandin 2014). There is no readily available explanation for this result; however, it may be due to other confounding handling procedures, cattle temperament or a case of the prod not being electrified when it was used at high levels. Further examination between the prodding of cattle at loading and transport shrink is necessary before conclusions can be drawn; the replacement of electric prods with flags, sorting boards or rattle paddles is still recommended based on previous study results (Le Neindre et al. 1996; Grandin 2001; Huertas et al. 2010; AMI 2012). The scores presented by Warren et al. (2010) and María et al. (2004) were not associated with the outcomes in this study, regardless, improving those score loads could still result in reduced stress on the cattle and fewer dark cutting animals according to results of the aforementioned studies.

In the current study, lairage time and wait time did not significantly impact severe bruising in the final multivariable model (Table 4.1). Yet, the combination of the two, total wait time, did have a significant relationship ($P < 0.0052$). In fact, as the total wait time increased by an hour (up to 5 h) the odds of severe bruising was decreased (OR = 0.8). Strappini et al. 2010 also reported that as lairage time increased from 6 to 24 h the bruising decreased (OR = 0.6; P <000.1). In contrast, other studies have found that, individually, increased lairage time or increased wait time is detrimental to animal outcomes (Goldhawk et al. 2014d; Romero et al. 2013). But these negative outcomes were when the wait time surpassed an hour and the lairage time surpassed 12h. Possibly there is an appropriate total wait time, which combines a short wait time (less than 60 min) and a sufficiently long lairage time (between 5 h and 12 h). When deciding on the appropriate total wait time, the shrink should also be considered, especially if feed is not offered to the cattle in lairage. After 12 h of feed and water deprivation, increased tissue shrink and increased dark cutting is probable (Jones et al. 1990; Hogan et al. 2007).

The amount of severe bruising is affected by the position measured and the carcass yield of the animals. Cattle that are leaner (Y1) are likely to have greater severe bruising along their back, whereas, cattle that are fatter (Y2 or Y3) are more likely to have greater severe bruising along their loins.

Shrink and bruising both cost the cattle industry a substantial amount of money. If cattle are marketed on a live weight basis then shrink accounts for a loss in value of approximately \$102 per head (4.9% shrink x 655 kg x 3.19 \$/kg = 102.4 \$ per animal; Canfax 2014; González et al. 2012a). It should be noted, though, that shrink is generally a result of loss of gut fill and only when severe does it involve tissue shrink. Therefore, estimated losses may be an overestimation of the actual revenue loss because only high shrink rates resulting in tissue shrink would affect the value of the carcass. It is now common to market finished cattle on a grid (based on carcass yield and grade) rather than by live weight. Nonetheless, shrink indicates cattle stress and has been associated with carcass quality defects such as dark cutting. Bruising, alone, accounts for an approximate loss of \$2.1 per head because of trim removed from the carcass (NBQA 2013).

Based on the above discussion, there are a number of recommendations that can be made, which could result in improved animal welfare and improved profitability. Drivers should avoid driving at high speeds (> 90 km/h) on uneven roads and avoid routes that require lots of slow driving and stopping. Adoption of these recommendations will reduce vertical accelerations, which were linked to increased severe bruising in the current study ($P < 0.0052$). Drivers should also reduce stationary trailer time, for example just after loading or while waiting at the slaughter plant (especially on days that are unseasonably warm) because heat and humidity could build up in the trailer causing the cattle to either become too warm or to become wet which increases the risk of cold stress once the air movement increases when the trailer starts moving again. Drivers should be especially cautious of this relationship for the cattle in the nose compartment because of the low air movement. A possible method for mediating heat and humidity build up in the trailer is to park in an area where passive ventilation is not blocked by other parked vehicles. In summer, it has been suggested that cooling fans and sprinklers at the slaughter plant can substantially reduce the temperature increases in a trailer however this method is likely not necessary or practical during the winter (Heiller et al. 2014).

Drivers should also strive to keep journey durations at a minimum because of the link between journey duration and shrink ($P < 0.001$). Longer journeys also necessitate more stops by the drivers (for rest, food or because of construction) as was confirmed by the 10 stops that were made on long journeys but not on short journeys.

The recommended space allowance for finished cattle is at a k-value between 0.02 and 0.027; k-values between 0.035 and 0.05 should be avoided because of detrimental animal outcomes. The CARC (2001) and cattle transport experts (Grandin 2014) recommend that bedding be used in trailers and that electric prods not be used while handling cattle. During loading electric prods were sometimes used on over 50% of the cattle loaded into a trailer ($n = 4$ loads) and bedding was never used in this study, which means that there is certainly room for improvement on both of these management practices. However no link to improved outcomes was observed with either of these practices. In fact, increased prodding was associated with reduced shrink (*P* = 0.0012). Further, the likelihood of severe bruising increased when beta agonists were used were used on cattle in this study (*P* = 0.023). This connection between beta agonist use and bruising is counter intuitive because of previously confirmed links between beta agonist use and decreased carcass quality as well as the association between beta agonist use, reduced fat cover and increased bruising. When making management decisions, feedlot operators should balance the decision to use beta-agonists both on its production-enhancing qualities and on its relationship with reduced carcass and meat quality traits confirmed in other studies. Further research on the relationship between beta agonists and severe bruising in cattle is necessary to uncover the cause of this link.

When considering the factors affecting shrink in this study it is important to keep in mind that the overall shrink was lower than average for cattle arriving at slaughter plants in Canada and the change in shrink was also quite small (2%) (NQBA 2013). A study with a larger range in resulting cattle shrink and increased replications could increase the researchers ability to explore the relationship between these variables.

Further research on the relationship between acceleration, physiological indicators of stress, and carcass quality would provide an even greater understanding of how the movement of the trailer affects cattle stress and balance during transport, especially if the measurements of acceleration (crest factor, vibration dose value, resonant frequencies and the power spectral density) were more comprehensive. It would also be informative to study the relationship between driving style, road conditions and accelerations experienced by the cattle, which could necessitate accelerometers on the cattle – not readily achieved using feedlot cattle or cull cows.

Cameras were not used in the present study because of the low and variable light levels and compartment configuration of the trailer. Recording video footage would also have been costly and time consuming to analyze in a study that was already highly involved and complex. Future studies could compare video footage of cattle inside trailers to specific events in the trailer (such as braking) to determine the effect of trailer motion on the cattle as investigated by Tarrant (1992).

In conclusion, improving cattle transport techniques is important for ensuring the social acceptability of beef cattle production, for improving the welfare of the cattle and reducing costly losses caused by poor transport conditions. Transport, if done improperly, can be associated with great stress, welfare issues and even death in cattle. It is also the cause of substantial economic losses due to shrink, dark cutting and carcass bruising. Criticism from the public can also be expected if scientifically sound evidence of good transport conditions for cattle cannot be disclosed. On the other hand, transport, if managed properly, can result in minimal stress, few welfare issues and minimal economic losses. By studying the characteristics of the cattle transported, handling techniques, in-transit conditions and post-transport outcomes, it is possible to provide a positive transport experience rather than a detrimental one. This thesis includes a comprehensive examination of specific cattle transport factors, their interaction with each other, their impact on carcass outcomes and ultimately the cost to the cattle industry. Hopefully, by the next beef quality audit, planned by the Beef Cattle Research Council in 2017-

2018 (BCRC 2015b), adoption of the transport practices recommended herein will lead to improvements in animal welfare and carcass quality.

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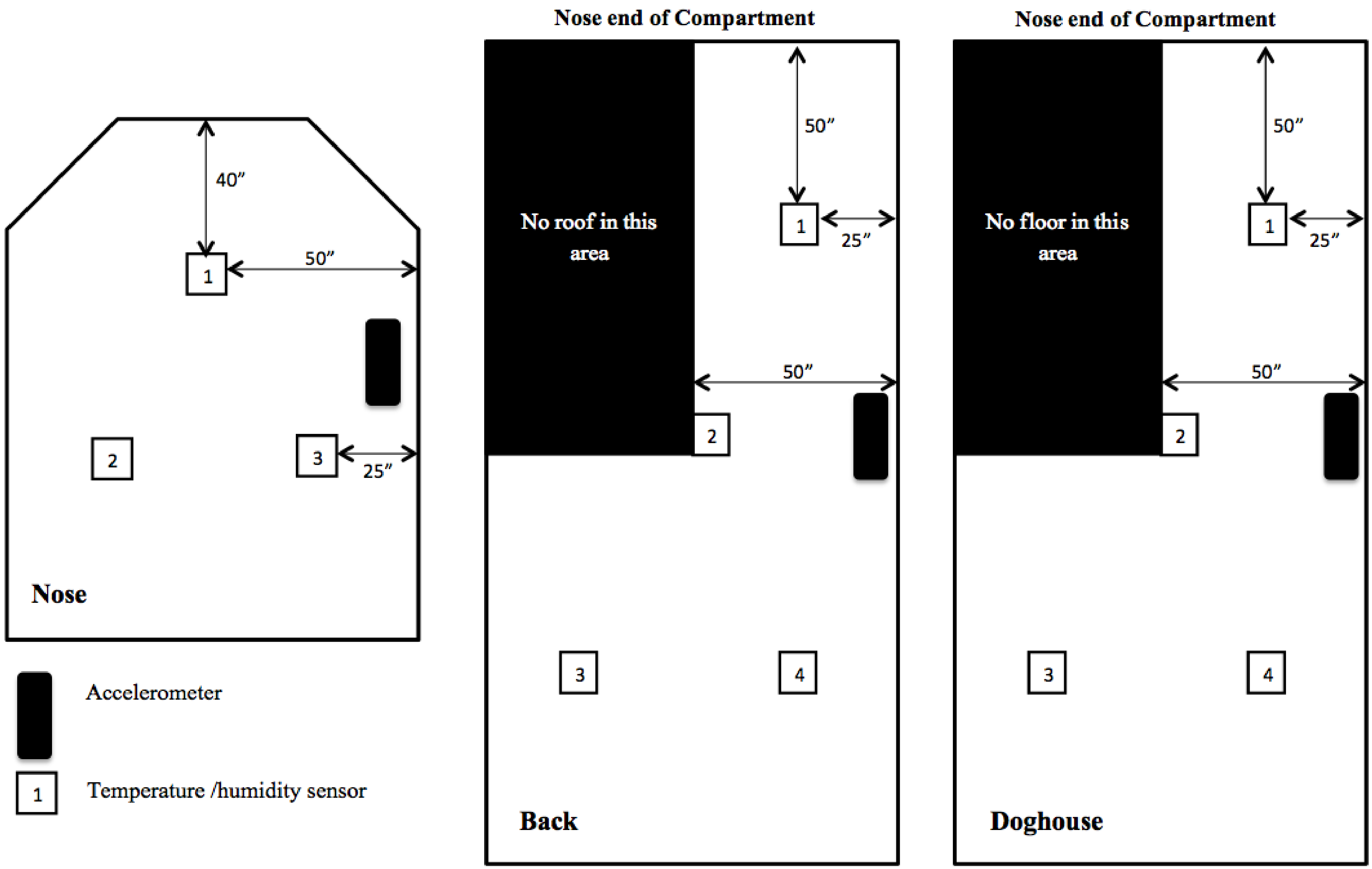
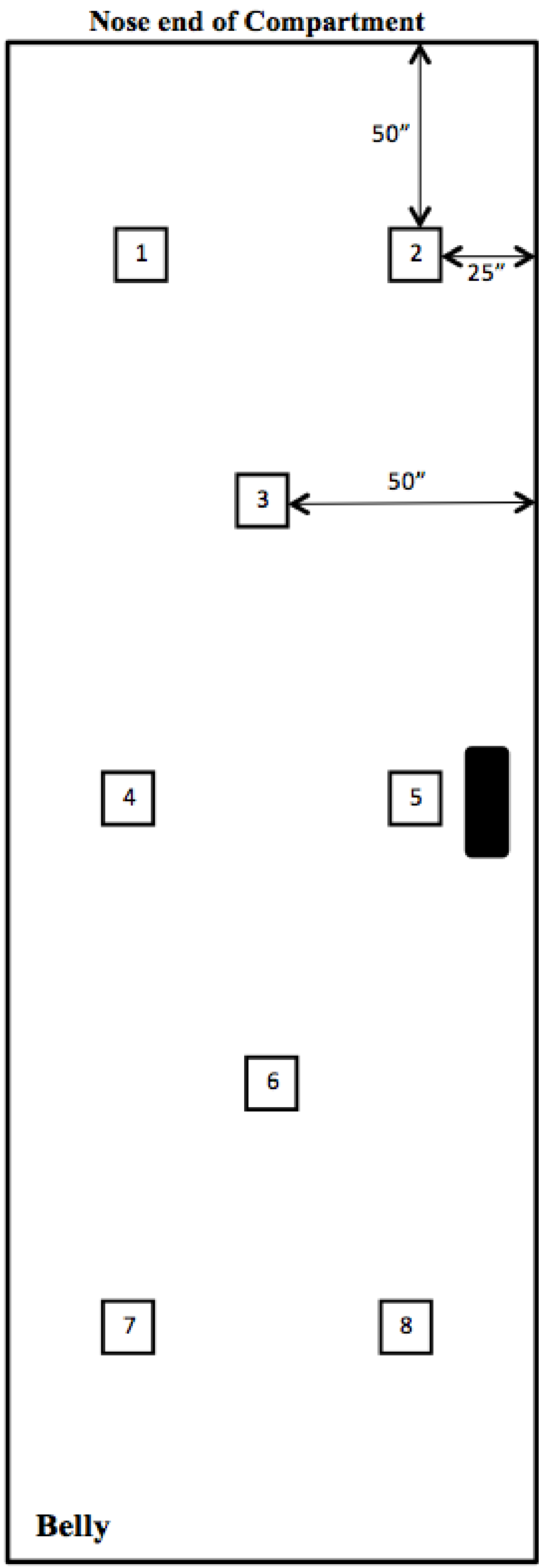
7. APPENDIX

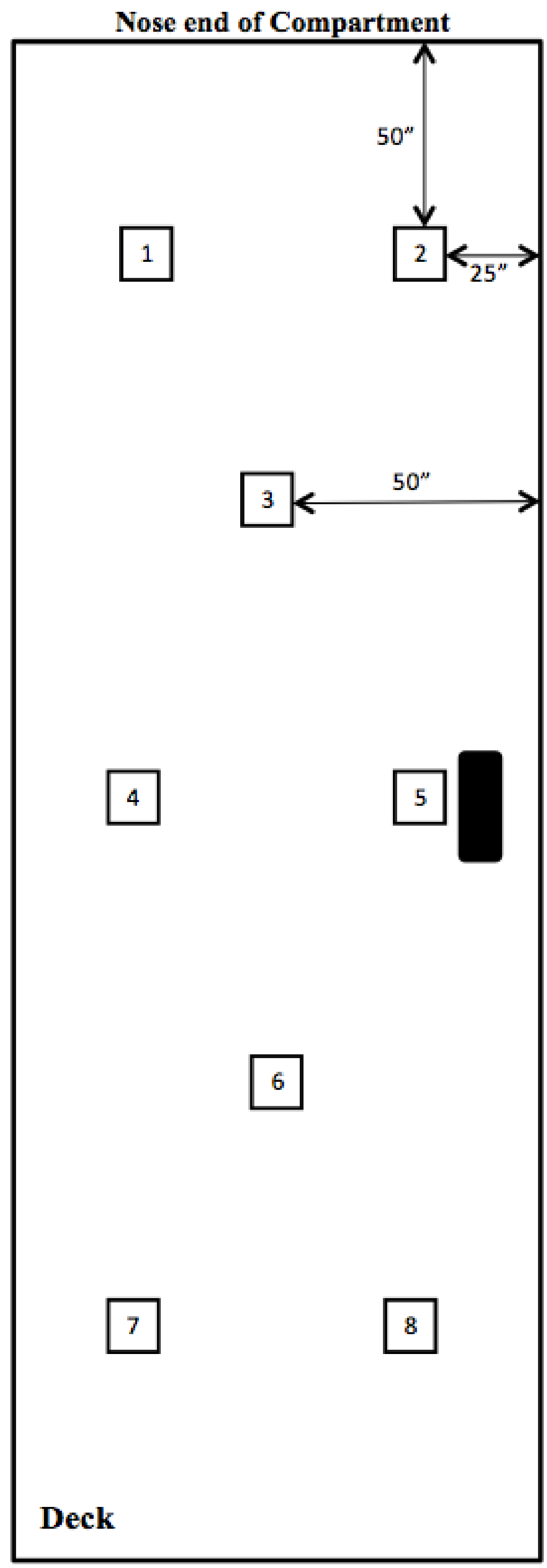
APPENDIX I – MANUSCRIPT II



Appendix 1. The position of temperature/humidity sensors and accelerometers on the livestock semi-trailers transporting finished cattle. Compartments are approximately to scale. Temperature/humidity sensors were attached to the roof of each compartment. Accelerometers were attached under the floor of each compartment to the crossbeams or framework.



Nose end of Compartment
50"
1
2
25"
3
50"
4
5
6
7
8
Belly



Nose end of Compartment
50"
1
2
25"
3
50"
4
5
6
7
8
Deck