DEVELOPMENT OF A MULTI-SCALE WALKOVER PLATFORM

FOR PRECISION LIVESTOCK MANAGEMENT

By

JORDAN DAVID FISCHER

Bachelor of Science in Biochemistry and Molecular Biology

Oklahoma State University

Stillwater, Oklahoma

2016

Submitted to the Faculty of the
Graduate College at
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 2019

DEVELOPMENT OF A MULTI-SCALE WALKOVER PLATFORM

FOR PRECISION LIVESTOCK MANAGEMENT

Thesis Approved:

Dr. John Long

____

Thesis Adviser

Dr. Ning Wang

____

Dr. Ryan Reuter

____

ACKNOWLEDGEMENTS

I would like to thank Jehovah for guiding me through this process. Thank you to Dr. John Long for taking me on as a Masters student and helping me through this thesis project, and the BAE department. Thank you to my family for their love and support through this journey. Thank you to Dr. Ryan Reuter for allowing me to use his facilities and personnel in this study, as well as Dr. Ning Wang for her guidance and materials to make this study work. Thank you to the Mike Fleming, Nick Sempter, and Wayne Kinner for building the Multi-Scale Platform. The OSU Dairy for letting me use their dairy cattle for this study.

Name: Jordan David Fischer

Date of Degree: April, 2019

Title of Study: DEVELOPMENT OF A MULTI-SCALE WALKOVER PLATFORM FOR PRECISION LIVESTOCK MANAGEMENT

Major Field: BIOSYSTEMS ENGINEERING

Abstract: Stocker Cattle Operations are a vital part of the beef cattle industry in Oklahoma. One of the most vital pieces of information for a stocker cattle operation is the weight of each individual management. Walkover Scales have long been used to predict the static weight of livestock from their dynamic walkover weight. However, current scales are a solid platform consisting of one scale and load bars. Single scales provide difficulty in distinguishing between cattle data during crowding events. Multiple scales in a row attempts to relieve this problem. A series of two scales and a series three scales were built to test this question. The series of scales, or a walkover platform, analyzed the walkover weight data from stocker cattle using various analysis methods.

TABLE OF CONTENTS

Chapter | Page

CHAPTER I 2
Portable Automated Sorting System (PASS) 2
Current Walkover Scales in Market 3
Crowding Events 3
Questions for this Study to Answer 4
Introduction to Beef Cattle Industry 4
Multi-Scale Walkover Platform Objectives 7
CHAPTER II 8
Scale Design and Construction 8
Data Acquisition and Data Processing methods 10
Accuracy of Scales 12
Sampling Rates 13
CHAPTER III 15
Walkover Scale Construction 15
Determining Required Dimensions 15
Rubber Mats 18
Top Plate 19
Top Plate Mount 25
OMEGA LCJA 1K Shear Beam Load Cell 26
Load Cell Spacer 28
Walkover Scale Frames 29
Scale Assembly 32
Multi-Scales 33
Two Walkover Scales 34
Three Walkover Scales 35
Electronic Hardware Setup 36
Software Flow 39
Calibration and Preliminary Data 42
Load Cell Calibration for 2 – Scale and 3 – Scale Beef Cattle 43
Load Cell Calibration for Dairy Cattle 44
Preliminary Data / Center of Mass Calculations 47
Sampling Process Design 49
Beef Cattle Data Collection 49
Dairy Cattle Data Collection 51
Data Preprocessing 53
Beef Cattle Data 53
Dairy Cattle Data 54
Data Analysis Methods 55
Successive Increase/Decrease in Data Values Analysis Method 55

Average Everything Between Analysis Method 57
Fast Fourier Transform (FFT) Analysis Method 58
Root Mean Square of the Frequency Analysis Method 60
Bland-Altman Limits of Agreement 61
CHAPTER IV 64
Preliminary Data / Center of Mass Calculations 64
Data Sets 65
Data Analysis 67
2-Scale Beef Cattle 69
3-Scale Beef Cattle 80
3-Scale Dairy Cattle 92
Long et al Analysis Method 103
CHAPTER V 104
Limitations 104
Conclusions 104
REFERENCES 109
APPENDICIES 111
APPENDIX A 111
APPENDIX B 113
APPENDIX C 115
APPENDIX D 116
APPENDIX E 122
APPENDIX F 125
APPENDIX G 126
APPENDIX E 127
APPENDIX F 129
APPENDIX G 131
APPENDIX H 132
APPENDIX I 133
APPENDIX J 137
APPENDIX K 141
APPENDIX L 142
APPENDIX M 143
APPENDIX N 147
APPENDIX O 151
APPENDIX P 152
VITA 153

LIST OF FIGURES

Figure **Page**

Figure 1 Types of Crowding Events……………………………………………………………………………………4
Figure 2 Beef Cattle Industry……………………………………………………………………………………………5
Figure 3 Tru-Test Walkover Platform and Load Bars……………………………………………………………13
Figure 4 Max DIM curve for X14…………………………………………………………………………………………16
Figure 5 Max DIM curve for Z8……………………………………………………………………………………………17
Figure 6 Positive Data Points (+) vs Negative Data Points (-)……………………………………………18
Figure 7 Top down view of Top Plate of Scales……………………………………………………………………19
Figure 8 XY coordinate plane per scale………………………………………………………………………………20
Figure 9 Bottom View of Top Plate………………………………………………………………………………………24
Figure 10 Top View of Top Plate Mount (left). Side View of Top Plate Mount (Right)………………25
Figure 11 Omega LCJA dimensions……………………………………………………………………………………26
Figure 12 Omega LCJA Specifications…………………………………………………………………………………27
Figure 13 Load Cell Spacer…………………………………………………………………………………………………28
Figure 14 Angle Steel Number 1001……………………………………………………………………………………29
Figure 15 Angle Iron Number 1002 (Top). Angle Iron Number 1003 (Bottom) ………………………30
Figure 16 Angle Iron Number 1004………………………………………………………………………………………31
Figure 17 Bottom View of; Middle Scale Frame (Left), End Scale Frame (Right) ……………………31
Figure 18 Bottom View of Scale Frames………………………………………………………………………………32
Figure 19 Individually Colored Scale Pieces in Scale Assembly…………………………………………32
Figure 20 Two Walkover Scales……………………………………………………………………………………………34
Figure 21 Three Walkover Scales…………………………………………………………………………………………35
Figure 22 WHEATSTONE BRIDGE (LOAD CELL WIRING) ……………………………………………………36
Figure 23 SPARKFUN LOAD CELL AMP: Top Side (LEFT). Bottom side (RIGHT) ……………………37
Figure 24 Adafruit Metro Mini 328………………………………………………………………………………………38
Figure25 Hardware Setup Per Scale……………………………………………………………………………………38
Figure 26 Hardware Setup for 3 Scales…………………………………………………………………………………39
Figure 27 Software Flowchart of Data Acquisition…………………………………………………………………41
Figure 28 498 lbs Cotton Gin Weight and Platform (LEFT). Calibration Platform (RIGHT)…………43
Figure 29 LC1 Calibration Data……………………………………………………………………………………………45
Figure 30 LC1 Calibration Curve…………………………………………………………………………………………45
Figure 31: 3 – scale Dairy Cattle excel table exmple……………………………………………………………47
Figure 32 Center of Mass coordinate plane…………………………………………………………………………48
Figure 33 Beef Cattle Data Collection Diagram……………………………………………………………………50
Figure 34 Dairy Cattle Static Weight collection. LEFT First ten sec. RIGHT second ten sec………52
Figure 35 Dynamic Walkover Data Tag 18500………………………………………………………………………53

Figure **Page**

Figure 36 Holstein 825 Complete Data Set……54
Figure 37 SID Analysis Method Generic Flow Chart……56
Figure 38 AEB Analysis Method Generic Flow Chart……57
Figure 39 FFT Time Domain (LEFT) vs Frequency Domain (RIGHT) ……58
Figure 40 FFT comparisons……59
Figure 41 Bland-Altman Example Plot……62
Figure 42 Example of Bad Walkover Scale Data……66
Figure 43 SID Analysis Method R-squared values……70
Figure 44 SID Analysis Method Mean Difference……70
Figure 45 2-Scale Beef Cattle SID StDev Difference……71
Figure 46 2-Scale Beef AEB R-squared……72
Figure 47 2-Scale Beef AEB Mean Difference……73
Figure 48 2-Scale Beef AEB StDev Difference ……74
Figure 49 2-Scale Beef FFT R-Squared……75
Figure 50 2-Scale Beef FFT Mean Difference……75
Figure 51 2-Scale Beef FFT StDev Difference……76
Figure 52 2-Scale Beef RMS R-Squared……77
Figure 53 2-Scale Beef RMS Mean Difference……78
Figure 54 2-Scale Beef RMS StDev Difference……78
Figure 55 2-Scale Beef Scale Accuracy Rankings……80
Figure 56 3-Scale Beef Cattle SID R-Squared……81
Figure 57 3-Scale Beef Cattle SID Mean Difference……82
Figure 58 3-Scale Beef Cattle SID StDev Difference……83
Figure 59 3-Scale Beef Cattle AEB R-Squared ……84
Figure 60 3-Scale Beef Cattle AEB Mean Difference……84
Figure 61 3-Scale Beef Cattle AEB StDev Difference……85
Figure 62 3-Scale Beef Cattle FFT R-Squared……86
Figure 63 3-Scale Beef Cattle FFT Mean Difference……87
Figure 64 3-Scale Beef Cattle FFT StDev Difference……88
Figure 65 3-Scale Beef Cattle RMS R-Squared……89
Figure 66 3-Scale Beef Cattle RMS Mean Difference……89
Figure 67 3-Scale Beef Cattle RMS StDev Differences……90
Figure 68 3-Scale Beef Scale Accuracy Rankings……92
Figure 69 3-Scale Dairy Cattle SID R-Squared ……93
Figure 70 3-Scale Dairy Cattle SID Mean Difference……94
Figure 71 3-Scale Dairy Cattle SID StDev Difference……95
Figure 72 3-Scale Dairy Cattle AEB R-Squared……96

Figure **Page**

Figure 73 3-Scale Dairy Cattle AEB Mean Difference……………………………………………………………..……96
Figure 74 3-Scale Dairy Cattle AEB StDev Difference……………………………………………………………………97
Figure 75 3-Scale Dairy Cattle FFT R-Squared……………………………………………………………………………98
Figure 76 3-Scale Dairy Cattle FFT Mean Difference……………………………………………………………………99
Figure 77 3-Scale Dairy Cattle FFT StDev Difference……………………………………………………………………100
Figure 78 3-Scale Dairy Cattle RMS R-Squared…………………………………………………………………………101
Figure 79 3-Scale Dairy Cattle RMS Mean Difference…………………………………………………………………101
Figure 80 3-Scale Dairy Cattle RMS StDev Difference…………………………………………………………………102

LIST OF TABLES

Table **Page**

Table 1: 2 – Scale Beef Cattle excel table exmple……………………………………………………………………42
Table 2 Preliminary Data……………………………………………………………………………………………………64
Table 3 Center of Mass (COM) Data……………………………………………………………………………………65

LIST OF EQUATIONS

Equation **Page**

Equation 1 Long et al. Period……11
Equation 2 Hamming Window……11
Equation 3 Dimension of Cattle from ASAE D321.2……15
Equation 4 Max Dimension of Cattle……16
Equation 5 Yield Strength……20
Equation 6 Maximum Bending Stress Allowed……20
Equation 7 Maximum Moment……21
Equation 8 Second Moment of Area……21
Equation 9 Safety Factor……22
Equation 10 Shear Yield Strength……22
Equation 11 Shear Stress……22
Equation 12 Deflection……23
Equation 13 Line of Best Fit for Calibration Curves……46
Equation 14 Convert 32-bit to Weight Value……46
Equation 15 X Distance for Center of Mass……48
Equation 16 Y Distance for Center of Mass……48
Equation 17 Amplitude Calculation for FFT analysis method……59
Equation 18 Frequency Calculation for FFT analysis method……59
Equation 19 Root Mean Square of the Frequency……60

CHAPTER I

INTRODUCTION

Incorporation of new technologies into current beef cattle productions has long been a ‘hot topic’ for researchers and a source of contention between researchers and producers. While researchers continue to perform studies on best management practices and develop new technology which could potentially benefit ranchers in their beef cattle production enterprise, the adoption rate of these practices and technologies is low. Specifically, one article states “profitability, managerial time or off-farm work and off-farm income, farm size, specialization, and human capital are all factors that have been determined to be significantly related to the adoption of innovations” (Johnson, Doye, Lalman, Peel, & Raper, 2008). Therefore, products produced for beef cattle operations need to address some or all of these factors, as well as incorporating new technologies into their product. One proposed product to address both issues of adoption rates and incorporation of new technologies would be a Portable Automated Sorting System, specifically for Stocker cattle operations.

Portable Automated Sorting System (PASS)

During initial discussion for the Portable Automated Sorting System (PASS), four objectives were determined which this product would have to perform:

1. Determine the weight of each animal using walkover scales.
2. Store the animal's information (Identification number, weight, sex, etc).
3. Sort the animals in the pasture based on setting provided by the owner/operator
4. Allow for portability to be used in various arenas of the cattle industry.

Each animal would need to be weighed at least every day, if not more than once a day. Each of these weights needs to be recorded and logged with the animal's identification number, for later use in decision making. The sorting system would need to be able to safely sort the cattle based on certain characteristics (weight, breed, sex, etc). Lastly, this system would have to be portable, either by being built on a trailer platform, or easily moved by farm equipment.

PASS would implement several technologies currently in use in the cattle industry; walkover scales for weighing cattle, automated sorting system, and allow for portability for implementation in various arenas in the cattle industry. Additionally, PASS could address some of the factors affecting adoption rates in the beef cattle industry. Theoretically, PASS helps to optimize the time of the owner, by both weighing cattle and sorting cattle without the need for the presence of the owner. Since PASS is a portable system, theoretically it could be moved between operations, or within various setting in an operation to best suit the needs of the owner. PASS also is specialized to the beef cattle industry as it is designed to operate solely with cattle. Finally, PASS could replace the responsibilities of employees on certain beef cattle operations, as PASS performs many of the tasks (weighing, keeping records, sorting) which are tasks an employee would conventionally perform.

Current Walkover Scales in Market

In researching the first objective, walkover scales were determined to be the prominent method to weight cattle in a pasture setting. Walkover scales allow each animal to move at their own pace, and not stress the cow by confining the animal in a closed system. Current walkover scales, such as the Walkover Weighing System (WOW) produced by Tru-test (Auckland, NZ) are a single scale system with load bars at the entrance and exit of the scale. These scales have several drawbacks which would make weighing the cattle in PASS difficult; load bars only measure front to back bias limiting the ability to track an animal over a scale as well as limiting the ability of a system to detect lameness in cattle, and a single scale system has difficulty weighing cattle during crowding events.

Crowding Events

Crowding events are defined as the occurrence of more than one animal on a walkover scale/platform. Different variations of crowding event occur. Peiper et al 1993, illustrates several of these crowding events in figure 1. The bottom orange arrow in figure 1 illustrates a crowding event where one animal steps onto the scale before another animal finishes stepping off the scale. The top orange arrow in figure 1 illustrates a different crowding event, where one and a half animals are on the scale, with no way of distinguishing between the dynamic weights of the individual animal. These are two instances of crowding events where data must be “thrown away” or not used because of an inability to distinguish between walkover weights of multiple animals. These two crowding events, as well as many more like them, led to several questions.

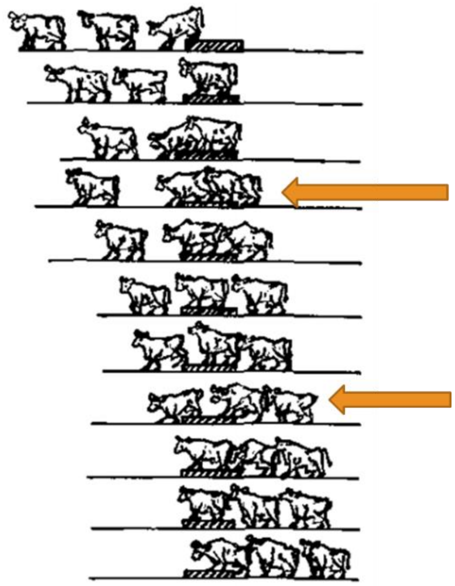


Figure 1 Types of Crowding Events.

Questions for this Study to Answer

1. Can a series of walkover scales be used to predict the static weight of an animal from their dynamic walkover weight?
2. How many scales are required for accurate prediction?
3. Can cattle weights be separated during crowding events using multiple scales?

However, to understand how to answer these questions, first one must determine why these questions should be answered.

Introduction to Beef Cattle Industry

To understand the need for walkover scales, it is first important to understand the beef cattle industry in the United States. There are three stages (operations) considered in the beef production chain; cow-calf, stocker/backgrounding, and feedlot (Peel, 2003). Cow-calf operations are responsible for conception, gestation, parturition, and the first six to ten months of life figure 2, reprinted from *Corn as Cattle Feed vs Humans* A. Broocks, 2017. Stocker/ backgrounding operations grow the animal for two to six months after leaving a cow-calf operation, and the feedlot operations are responsible for finishing the animal in four to six months after leaving the stocker/backgrounding operation (Broocks, 2017).

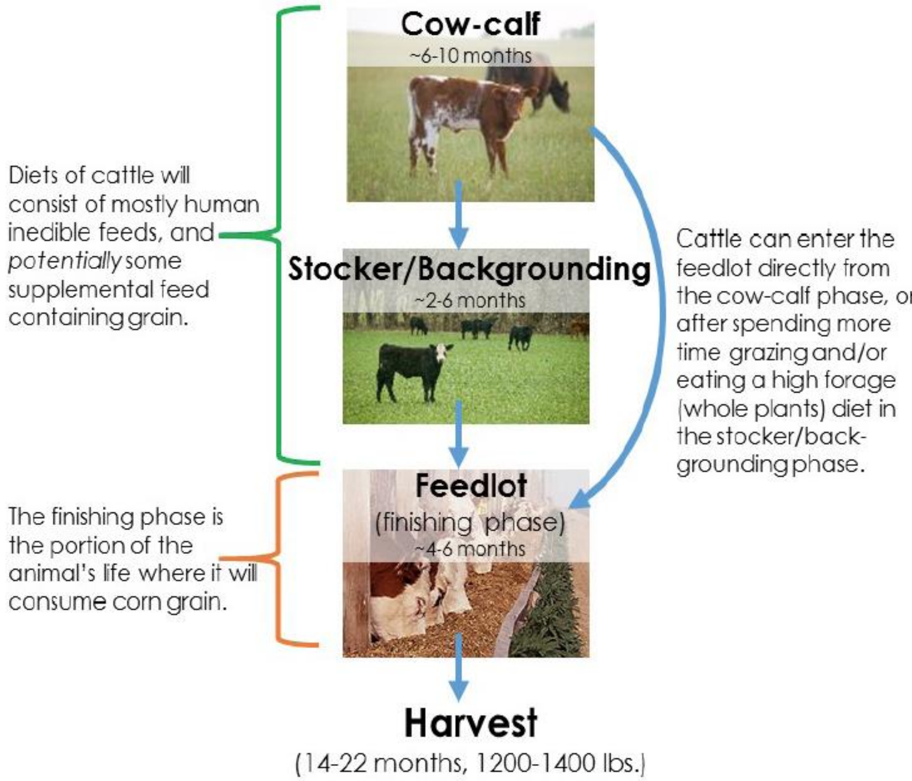


Figure 2 Beef Cattle Industry.

Since PASS is designed to operate in a pasture setting, feedlots were not considered when designing the system. Cow-calf operations, though generally in a pasture setting, were determined too difficult to weight and separate cows with calves, and therefore stocker/backgrounding operations were chosen as the operation in which to design PASS towards.

Stocker cattle is traditionally a southern U.S. term, while Backgrounding is often an northern U.S. term, both generally referring to cattle which are grown on forage-based rations (Peel, 2003), as opposed to feedlot cattle which are cattle that grow on a corn-based ration in confinement. Stocker cattle are often in some type of pasture based setting feeding off the forage provided to them.

Stocker cattle provide an important economic role, not only for the state of Oklahoma, but the whole of the beef cattle industry. Since beef cattle prices tend to cycle, particularly the cow-calf sector (spring calving and fall calving), the stocker cattle sector provides a buffer. These operations help maintain a semi-even flow of cattle from the cow-calf operations to the feedlots, then to slaughter houses from year to year (Peel et al, 2003). Additionally, stocker cattle provide the economic benefit of "forage-based gains" and "are the least expensive in the industry" (Peel et al, 2003, p. 377). Oklahoma in particular, and the southern Great Plains in general, host a great number of beef cattle. Over twenty-five percent of all beef cattle in 2010 were in the southern Great Plains, and Oklahoma was second only to Texas in the percentage of U.S. beef cow inventory, 6.6% and 16.4% respectively (McGrann 2010). These numbers show that stocker cattle are a large part of the beef cattle industry.

In the U.S. beef cattle industry, weight is a primary driving force in decision making. Cattle which weigh too low for the next phase of production are both discounted when bought and often underperform in regards to weight gain. Additionally, when cattle weigh more than expected, it is likely the owner has lost money, as it would have been cheaper to move the animal sooner to the next phase of production, and the next phase will likely have to sort these animals out and feed them separately, therefore costing extra time and money. The optimum weight for movement between stocker stage and feedlot stage vary depending on corn prices and market prices of beef cattle; one article states stocker cattle range from 300 lbs to 800 lbs (Peel,2003, McGrann, 2007). Since the beef cattle industry is driven by weight and the weight range of cattle in stocker operations varies greatly, operators need to accurately measure and record the weight of stocker cattle as they grow.

Additionally, collection and maintenance of weight records of individual cattle assists in individual cattle management. Individual cattle management falls into a broader category of 'Precision Livestock Management', a management practice in which owners manage livestock on an individual basis, rather than the traditional herd basis. Precision Livestock Management allows for a more precise timing of supplements and medicine to individual livestock which are ill or need specialized attention by an owner, reducing waste, and allowing for better record keeping and responsibility appropriation in livestock industries. Specifically, the ability to detect illness in cattle is assisted by the measurement of weight loss, or at least a reduction in the average daily weight gain of an animal, measured by walkover scales.

Multi-Scale Walkover Platform Objectives

Since walkover scales are an important piece in Precision Livestock Management, and current walkover scales have some draw backs, this study attempts to determine in multiple scales can be placed in a row and accurately predict the static weight of an animal from their dynamic walkover weight. The multi-scale walkover platform has several objectives:

1. Accurately predict the static weight of individual cattle from their dynamic walkover weight.
2. Separate cattle data during crowding events
3. Measure center of mass of front and back half of cattle

CHAPTER II

REVIEW OF LITERATURE

Several methods for both construction of walkover weighing systems and processing of walkover data have been developed through the years. This section will discuss several of them while examining and analyzing several variables required for a successful walkover scale system.

Scale Design and Construction

Over the years, researchers have developed many different walkover scales to predict the static weight of an animal. While the lengths and widths of each scale has differed slightly, the design goals are generally the same; create a narrow walkway which is long enough to gain enough data points for accurate prediction of static weight from an animals dynamic walkover weight, while being short enough to keep from having multiple animals' on the scale at the same time (a crowding event), and therefore increasing the difficulty in separating walkover data between animals (Filby et al., 1992).

From research, length of scales vary, with the shortest being 2.1 m (Ren et al., 1992) and the longest being 3.5 m (Long, Takahata, Umetsu, Hoshiba, & Takeyama, 1991). Moreover the width of walkover scales to vary with the narrowest being 0.75 m wide (Long et al., 1991) and the widest being 1.2 m. Though these vary in width, these scales are generally narrow. It is important to keep in mind that with walkover scales, not only are attempts made to keep the animals from stepping on the scales at the same time, but in the event multiple animals are on the scale at the same time, it is undesirable for the second animal to squeeze by the first animal, and cause incorrect data measurement and readings. Therefore narrow scales are needed to force a single file line of cattle through the walkover system. Since the size of the walkover scales differed between studies, it was normal for us to assume that the quantity, size, and type of load cells varied between each study, also. Filby et al. (1979) utilized a hanging platform attached to an overhead pivot, attached to a pivot arm and finally to a 0.5 ton tension load cell (p. 69). Long et al. (1991a) used four compression type load cells, one at each corner of the platform, while Ren et al. (1992) and Peiper et al. both used two load bars in their study (load bars support two adjoining corners of a platform, hence the reason only two load bars are necessary). Other, more recent studies, using walkover scales and walkover scale systems used the Walk Over Weighing (WoW) scale system (Alawneh, et al., 2011; Dickinson et al., 2013; González-garcía et al., 2018; González-García et al., 2017; Gonzalez, et al., 2014; Wishart, et al., 2017) which utilize two MP600 load bars by Tru-Test Limited (Auckland, NZ),. It may be beneficial to note that the WoW system is 2.2 m long by 0.50 m wide at the walkover scale and 0.718 m wide overall, and uses two load cell bars. However, none of these studies or current systems utilizes multiple scales or platforms to predict the static weight of cattle from their dynamic walkover weight.

Additionally, there seems to be limited academic research on walkover scales with multiple scale platforms, which is why there are none mentioned in this literature review. Yet, from these articles a multi-scale walkover platform can be designed and tested, using these same considerations. The multi-scale walkover platform is similar to the single scale platform in overall length, but with multiple scales, weight one end of the platform does not affect the weight readings on the other end of the platform as with single scale walkover systems.

Data Acquisition and Data Processing methods

In addition to knowing how previous studies have built their single walkover scales, it is equally vital to know and understand how these studies acquired and processed the information provided by the scales to predict static weights. Several combinations of data analysis have been used to predict the static walkover weight of an animal from their dynamic walkover weight. Most studies use an averaging technique with the data readings from the walkover scales. Studies only average data readings when all four of the animals legs are on the scale are used for averaging (Filby et al., 1979; Long, et al., 1991a; Peiper et al., 1993; Ren et al., 1992).. What differs between studies is the decision of when all four of the animal's legs are on the scale. (Filby et al., 1979; Long, et al., 1991a; Peiper et al., 1993; Ren et al., 1992).

Filby et al. 1979, utilized "two active filter stages A2 and A3 and components were chosen to give a cut-off frequency of about 0.5 Hz with attenuation above this frequency of 24 dB/octave" (p. 71). Effectively, through circuit construction (capacitors and operational amplifiers), the peak voltage output from the load cell is stabilized and allowed to remain constant. This peak voltage is attributed to a known weight from the load cells. The weight calculated from the voltage output is averaged in a digital panel meter to eliminate the low end frequencies such as little movements of the animal through the weighing system. The averaged weight is transmitted from digital panel meter to a computer and stored along with the animal's identification number.

The data collected by Long et al. 1991a, passed through an analog 1 Hz low-pass filter before entering into the data processing system. This study used a different averaging technique, the Hamming window, over an effective region or period. The period chosen within the weight signal was the time between the peaks in the data signals, or one full gate during walkover. For example, placing the first front hoof on the scale creates a peak. Therefore, the selected period is the time between the first front hoof being placed on the scale to the second time the same front hoof is placed on the scale, or one complete gate of the animal (Long, et al., 1991a). Equation 1 describes this period (P):

$$P = \eta * P_{max} \quad (1)$$

$\eta = 0.8$

P_{max} = is the value of the highest peak in the period (kg)

The Hamming window is performed over this period. The Hamming window "can effectively filter the transformed signal in the frequency domain thus reducing the effect of the fluctuations resulting from movements of the animal on the scale platform" (Long, et al., 1991a, p. 36). The Hamming window is defined in Equation 2:

$$w(n)\ 0.54 + 0.46\cos(2\pi n/N) \quad (2)$$

$n = -N/2, \ldots -1, 0, 1, \ldots, N/2$

N = width of the window

The data produced by the Hamming window is then averaged and the predicted static weight of the animal is obtained.

The predominate method for static weight prediction from dynamic weight readings is the averaging of the data points obtained when all four of the animals legs are on the scale. Ren et al. 1992 stated "the average of the data points representing a cow's four-leg weight is an acceptable value for the true weight of the cow. The problem is how to locate the starting and ending points of the data set. Ren et al 1992 uses reference weights (previously calculated static weights) to begin and end their data averaging array. There are two reference weights stored for each animal, one for the morning and one for the evening, because an animal can change more than 10% in body weight throughout the data (Maltz 1990). When the scale system reads the ID number, the reference weight is obtained from the reference table. The current data set is read line by line and the data array for averaging begins when the current data is within 10% of the reference weight. All subsequent data points are inserted into the data array for averaging until the current data falls outside of the 10% previously mentioned (Ren et al., 1992). This study asserts that a minimum of eight data points is necessary to predict the static weight of the animal (Ren et al., 1992).

Peiper et al. 1993 utilizes an averaging technique of successive data readings. "Load cell values are continuously sampled; once an increase of successive values is detected, sampled weights are stored in memory (into array W) until a decreasing trend is detected. The decreasing trend is indicated if there were five successive decreases in the load cell values. This decrease indicates that the cow has started to step off the scale plate. The average of the accumulated load cell values prior to decrease is then calculated in order to derive the 'true weight' which is then stored in memory as the weight of the cow i (W[i])" (Peiper et al., 1993, p. 16).

Accuracy of Scales

Various accuracies are suggested throughout literature. Filby et al. 1979 stated their cattle weighed between 400 kg and 800 kg., Peiper et al. 1993 cited an article (Maltz, Kroll, Spahr, Devir, & Sagp, 1991), which specified Fresian dairy weight as typically being between 400 and 800 kg. With this information, Filby et al. indicates an accuracy for their walkover scale of ±2% of body weight, while Peiper et al. advised an accuracy of ±1% of body weight. When performing calculations using the 400 kg and 800 kg cattle, the accuracies suggested from these studies calculate to be ±8 kg to ±16 kg for the Filby study, and ±4 kg to ±8 kg for the Peiper et al study. Long et al. 1991a, took this a step further and suggested an accuracy of ±2kg of bodyweight at every walkover data set, but found "about 90% of the walk-through weights are within the static weights ±3 kg" (p. 37). Additionaly, Filby et al. 1979 and Ren et al. 1992, noted that their studies required averaging of multiple walkover or walk-through readings, four and six respectivley, to estabilish accurate predictions of the animals true static weight. Lastly, Long et al. 1991 indicated in their study that a minimum of 10 kg must be produced by the scale system to assume that an animal is on the scale.

The MP600 weight bars used in the Tru-Test weighing platform are accurate at "±1% or two resolutions, which ever is greater" (Tru-Test, n.d.). The MP600 load bars (right side of figure 3) from Tru-Test Auckland, NZ which go under the entrance and exit of their walkover weighing systems (left and center of figure 3). Left and center pictures in figure 3 are reprinted from *2.5m WOW Cattle Platform* Tru-Test Auckland, NZ, and the right picture in figure 3 is reprinted from *MP600* Tru-Test Auckland, NZ.

Figure 3 Tru-Test Walkover Platform and Load Bars.

Sampling Rates

The frequency of sampling (Hz), or number of data points per second, of the load cells for averaging data is very important, too little and there will not be enough data points for averaging and the predicted static weight will be wrong, too many and the electronic control systems may not be able to handle the quantity of data. One study suggested using the Sampling Theorem (Long et al., 1991). The Sampling Theorem contends that the frequency of sampling needs to be at least twice as often as the frequency of input by a system. Specifically, if multiple inputs occur in a single system, the sampling rate needs to be twice the rate of the greatest input rate. The study went on to use a 50 ms sampling interval, or 20 Hz, to meet the theorem (Long, et al., 1991a).

Ren et al. 1992, specified the A/D converter in their electronics setup allowed for either 20 Hz or 140 Hz. Their study required a minimum of 0.5 sec of the animal being on the platform with eight data points being necessary to determine a reliable average weight (Ren et al. 1992). When performing mathematical computations, a frequency of 20 Hz yields a data point every 0.05 sec, with eight data points occurring every 0.40 sec. A frequency of 140 Hz yields a data point every 0.007 seconds, with eight data points occurring every 0.056 sec. These computations suggest the study used a frequency of 20 Hz.

Though the walkover scale study performed by Peiper did not specifically state the sampling rate of the load bars, the study did state the “weighing system produced an output every 0.4s which was calculated as the average reading of the load cell during the last 0.4s” (Peiper et al., 1993, p. 16). Therefore the calculated sampling frequency of the load bars was 2.5 Hz.

As seen from the literature, size of scale and methods for predicting static weight varies greatly. This study plans on using these methods as well as other methods to determine if static weights can be predicted from dynamic walkover weights using multiple scales.

CHAPTER III

METHODOLOGY

Walkover Scale Construction

Determining Required Dimensions

The scales were designed using ASABE standards (ASAE D321.2), specifically using the dimensions from section 2 subsection 2.2. The standards indicate these dimensions are specifically for beef steer cattle. The assumption was made that the largest animal to walk across these scales would weigh no more than 2000 lbs (907.18 kg), and the overall dimension of the multi-scales would accommodate 1.5 times the calculated length of the animal. The generic formula given by the standards, (ASAE, 1985, p.3) is

$$DIM = 10[A + B\,(WT) - C\,(WT)^2] \qquad (3)$$

DIM = dimension (mm)

WT = weight (kg)

A, B, and C = constants listed in Table 2 of standards page

DIM is then added to by the Percent Error times DIM. The equation looks like

Max DIM = DIM + DIM * Percent_Error (4)

Max DIM = maximum dimension of animal (mm)

DIM = Dimension (mm)

Percent_Error = Percent Error of constants from Table 2 of standards page

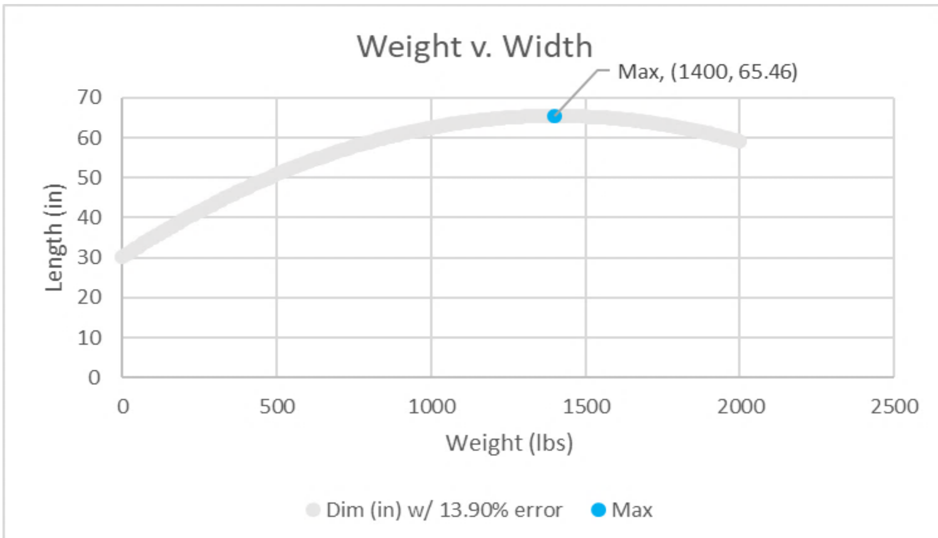


Figure 4 Max DIM curve for X14.

In Table 2 of ASAE standard D321.2, reference point X14 is the longest point of reference for the lower part of the body and the constants listed as A = 67.44, B = 0.2466, C = 193.57 x 10^6, Percent Error = 13.9 (p.6). When these constants are inserted into equation 4, along with various weights the curve in figure 4 is formed. To accommodate for the largest possible animal length, the maximum length 65.46 inches (blue dot) in figure 4, which corresponds to a weight of 1400 lbs. The approximate length between the brisket and the snout of the animal is not given in the ASAE D321.2 standard, and therefore an additional ten inches is added in an attempt to accommodate for the head and neck of each animal. The resulting length of the largest potential animal used in the design of the multi-scale walkover platform is 75.50 inches. Each scale is designed to weight half an animal at a time (front half or back half), therefore the maximum length (75.50 inches) in split in half, resulting in the length of each scale to be 37.75 inches (figure 7).

Again looking at Table 2 in ASAE D321.2 for reference point Z8, constants are listed as A = 24.98, B = 0.1552, C = 95.06 x 10^6, Percent Error = 11.3 (p.6). Inserting these constants into equation 4 and converting the numbers to inches, 'Max DIM' equals 37.33 inches. to allow for the largest possible animal to fit completely over the scales, the maximum width of 38.70 inches (blue dot in figure 5), which corresponds to 1800 lbs was chosen for the width of each scale. Since reference point Z8 is the widest reference point in ASAE D321.2 and the widest overall point of an animal, no additional width was added to the scales.

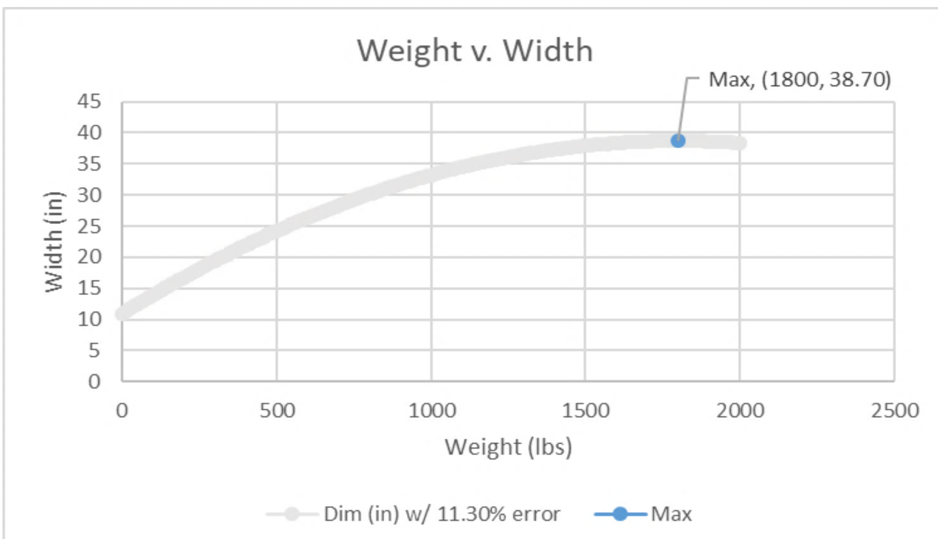


Figure 5 Max DIM curve for Z8.

Load cells are a vital part of any scale system. Load cells are used to measure the amount of force being applied to an object. With scales, load cells measure the amount of weight (force exerted downward) by an object. This study utilized Omega LCJA-1K Heavy Duty Shear Beam Load Cell to measure the weight of animals walking across the scales. Each load cell has the capacity to measure + 1000 lbs to – 1000 lbs. As illustrated in figure 6 the deflection of the load cell downward is considered positive data, while the deflection of the load cell upwards is considered negative data.

These load cells were chosen for several reasons. This first, shear beam load cells are simple to secure to a frame. Two, these shear beam load cells from Omega are water and dust proof, and lastly, the 1000 lbs load cells were chosen because the 500 lbs shear beam load cells were out of stock.

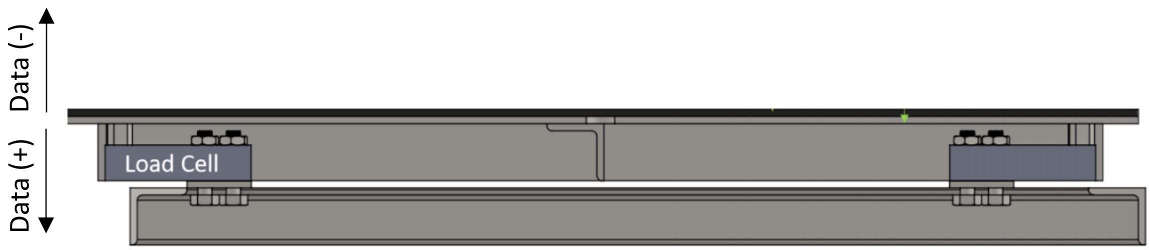


Figure 6 Positive Data Points (+) vs Negative Data Points (-)

All of the metal work (except the load cells) is manufactured out of mild steel and built by the Biosystems and Agricultural Engineering Metal Fabrication Ship at Oklahoma State University.

Rubber Mats

Livestock-grade rubber mats were purchased from Tractor Supply in Stillwater, OK. The mats purchased measure 48” x 36” x 1/2”. Since it was likely for the cattle to walk down the center of the scales, the decision was made to line the 36.00 inch up with the longer (38.25 inch) scale and cut the 48 inch down to 37.75 inches thus covering the entire length of the scale in the direction the cattle were traveling.

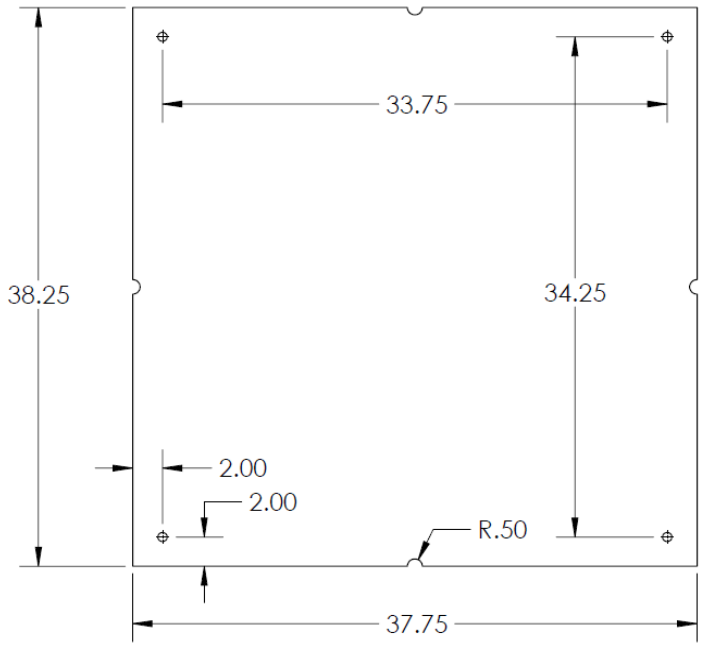


Figure 7 Top down view of Top Plate of Scales. All numbers are in units of inch.

Top Plate

The top plate for an individual scale measures 38.25 inches tall by 37.75 inches wide (figure 7). The thickness of the top plate is 0.25 inches. Holes were drilled for the top plate to sit on top of the load cells at each corner. The holes measure 0.625 inches in diameter and are centered at 2.0 inches from the edge of the top plate (figure 7). The width distance (y-axis, figure 8) between load cells is 34.25 inches, while the length distance (x-axis, figure 8) between the load cells is 33.75 inches. Centered on each side of the scale are semicircles with a radius of 0.5 inches. These semicircles are cut to provide lift points for hooks, so the hooks will not slide off the scales during lifting. Each Top Plate with welded angle weighs approximately 120 lbs.

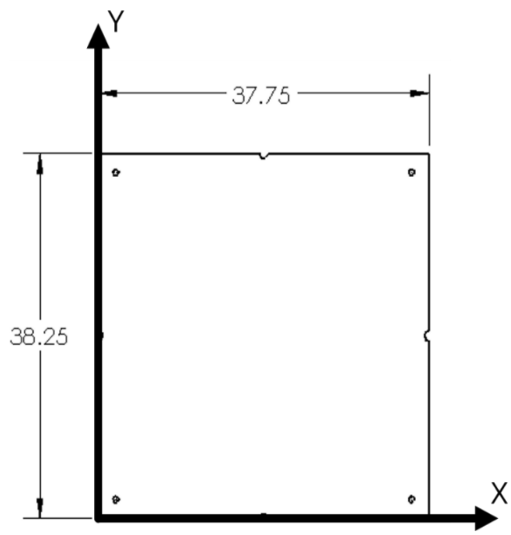


Figure 8 XY coordinate plane per scale.

For the Top Plate of the scales and angled steel, two bending stresses were calculated. One using the x-axis (37.75 in side) cross-section and one using the y-axis (38.25 in side) cross-section (figure 8). It was assumed the maximum force seen by the Top Plate would be 2000 lbs point load at the center of the Top Plate. To calculate the maximum allowable bending stresses for the Top Plate, Budynas 2015 indicates the maximum bending stress (σ_{max}) cannot exceed the yield strength (S_y). This concept is illustrated in equation 5.

$$S_y \geq \sigma_{max} \quad (5)$$

S_y = Yield Strength of material [1018 Hot Rolled (HR) Steel = 32,000 psi]

σ_{max} = maximum bending stress allowed by a particular material (kpsi)

The maximum bending stress is defined in equation 6.

$$\sigma_{max} = M_y / I \quad (6)$$

σ_{max} = maximum bending stress allowed by a particular material (kpsi)

M = maximum bending moment on object (lbf*in)

Budynas 2015 defines M as the bending moment of an object. The equation for M for this study assumes a maximum bend where the force being placed on the Top Plate is in the exact center of the plate. This maximum bending stress (M) is defined in equation 7.

$$M = F * 0.5l / 2 \tag{7}$$

M = maximum moment placed on object (lbf*in)

F = maximum force placed on object (psi)

l = length of object (in)

In addition to finding the maximum moment seen by the Top Plate, the moment of inertia (I) is needed to calculate the maximum bending stress. The moment of inertia for the Top Plate can be defined by equation 8 (Budynas, 2015)

$$I = b * h^3 / 12 \tag{8}$$

I = second moment of area (in^4)

b = length of object (in)

h = height of the object (in)

Since the Top Plate is simply supported by the Top Plate Mount, the distance between the load cells on the x-axis is 33.75in (figure 7), and the distance between the load cells on the y-axis is 34.25in (figure 7). Assuming a maximum Force of 2000 lbs, the moment placed on the x-axis(figure 8), designated as M_x, is 16875 psi, and the moment placed on the y-axis (figure 8), designated as M_y is 17125 psi.

The moment of inertia (I) for the Top Plate and the angled steel is calculated using the Parallel Composite Theorem. Since the Top Plate and angled steel pieces were designed in Solidworks, a 3D drawing program, the moment of inertia is calculated under the 'Section Properties' function. The moment of inertia of the area, about the centroid (I) for the x-axis is 0.80 in^4. The moment of inertia of the area, about the centroid (I) for the y-axis is 1.49 in^4.

Using equation 6, the maximum bending stress seen by the x-axis is the maximum moment seen by the Top Plate (M) and the second moment of area (I) for each axis, the calculated maximum bending stress for the x-axis (σ_x) to be 21093.75 psi, and the maximum bending stress for the y-axis (σ_y) to be 11493.29 psi.

Using equation 6, both of these maximum bending stresses (σ_x and σ_y) are less than the yield strength of 32,000 psi. Factor of Safety for bending stresses can be defined using equation 9.

$n = S_y / \sigma$ (9)

n = factor of safety

σ = maximum bending stress seen by object (kpsi)

S_y = yield strength of material (psi)

Factor of safety for bending stresses on the x – axis is 1.52, and the y – axis is 2.78. The overall factor of safety for bending stresses for the Top Plate is the lowest factor of safety calculated, n = 1.52.

To calculate the maximum allowable shear forces on the Top Plate, this study used the Max Shear Stress Theory (MSS) equations from Budynas 2015. This theory says that an object will yield if the shear stress (τ) exceeds the half of the yield strength (S_{sy}) of the material from which the object is derived. Equation 10 illustrates this point.

$S_{sy} \geq \tau$ (10)

S_{sy} = Shear Yield Strength = 0.5 * S_y = [1018 Hot Rolled (HR) Steel = 16,000 psi]

τ = Shear Stress on object (psi)

$\tau = F / A$ (11)

τ = Shear Stress (psi)

F = Maximum Force seen by the object (psi)

A = Cross-sectional Area of objects (in^2)

The cross-sectional area for the x – axis is calculated in Solidworks as 10.37 in^2, and the cross-sectional area for the y-axis is 11.42 in^2.

Shear stress calculated (equation 11) for the x-axis was found to be 192.86 psi and the shear stress calculated for the y-axis was found to be 175.13 psi, both of which is well below the yield strength of 16,000 psi shear yield strength for 1018 HR steel.

Lastly, the deflection of the Top Plate downward into the load cells needed to be taken into consideration. Budynas, 2015 provides the equation 12, which calculated deflection downwards on a beam which is simply supported.

$$Y = F * x *(4x^2 – 3d^2) / (48EI) \quad (12)$$

Y = amount of deflection (in)

F = Force on object (psi)

x = distance from edge of object to point of interest (in)

d = total length of object (in)

E = Young's Modulus for material of object (psi)

I = second moment of area (in^4)

Since the load cells orient parallel to the x –axis and the load cell mount spans the entire width of the load cell, only the deflection in the x – axis is calculated to determine if interference will occur when a 2000 lbs animal stands in the middle of the scale. The numbers used in equation 12 are F = 2000 lbs, x = 4.625 in (distance from read end of load cell to center of Top Plate mount), d = 33.75 in (distance between load cell mounts), E = 30,000,000 psi for steel, and I = 0.80 for the x – axis. Using equation 12 with these numbers yields a deflection downward at the rear end of the load cell to be 0.0268 in. The normal distance between the load cell and the bottom of the Top Plate is 0.75 in, therefore there will not be any interference between the Top Plate and the load cells during periods of loading (animal on the scale).

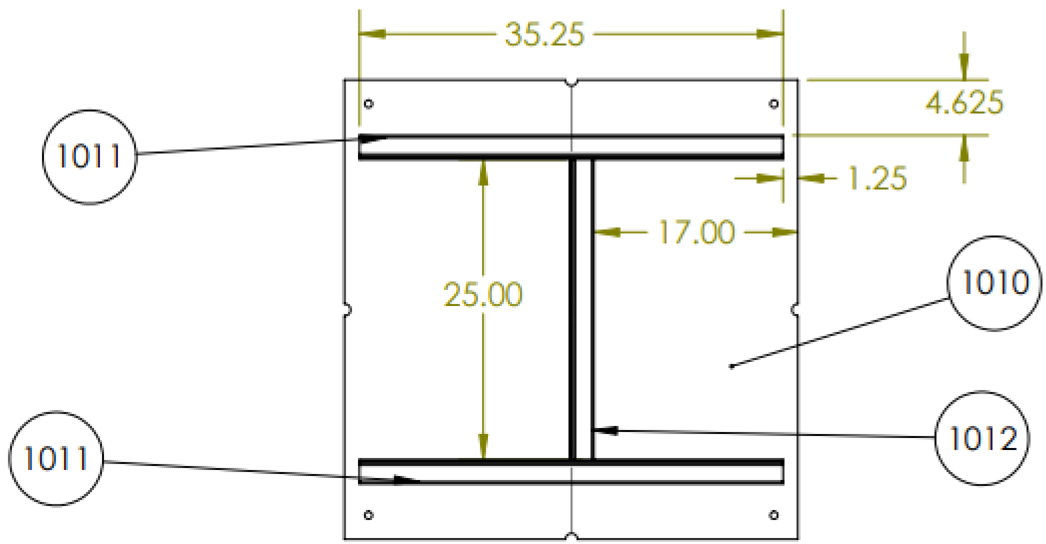


Figure 9 Bottom View of Top Plate. All units for numbers is inches.

As previously mentioned, the bottom side of the Top Plate has mild steel angle welded to add rigidity, see figure 9. The mild steel angle supports measure 0.25 in x 2 in x 2 in, where 0.25 in is the thickness, and each of the 2 inch dimensions are the width of each leg. The length of the angled steel pieces' changes between items 1011 and 1012 (figure 9). Item 1011 is 35.25 inches and is set 4.625 inches from the 37.75 in top edge of the Top Plate (figure 9), and 1.125 inches from the 38.25 in edge of the Top Plate. One face of the angle meets the bottom of the Top Plate, while the other face is turned inwards meeting the edge of item 1012. Orienting the second face of the angle allows for greater surface for welding the two items together and increasing overall strength. Item 1012 (figure 9), is 25.00 inches long and sits between both of the 1011 pieces. Additionally, 1012 is set 17.00 inches from one of the 38.25 inch sides. Each piece of angle has two-inch welds with six-inch spacing's on both sides of the face that meets the bottom of the top plate. For reference, the cattle traveled from left to right in figure 9. In other words, the cattle traveled parallel to item 1011 and perpendicular to item 1012.

Top Plate Mount

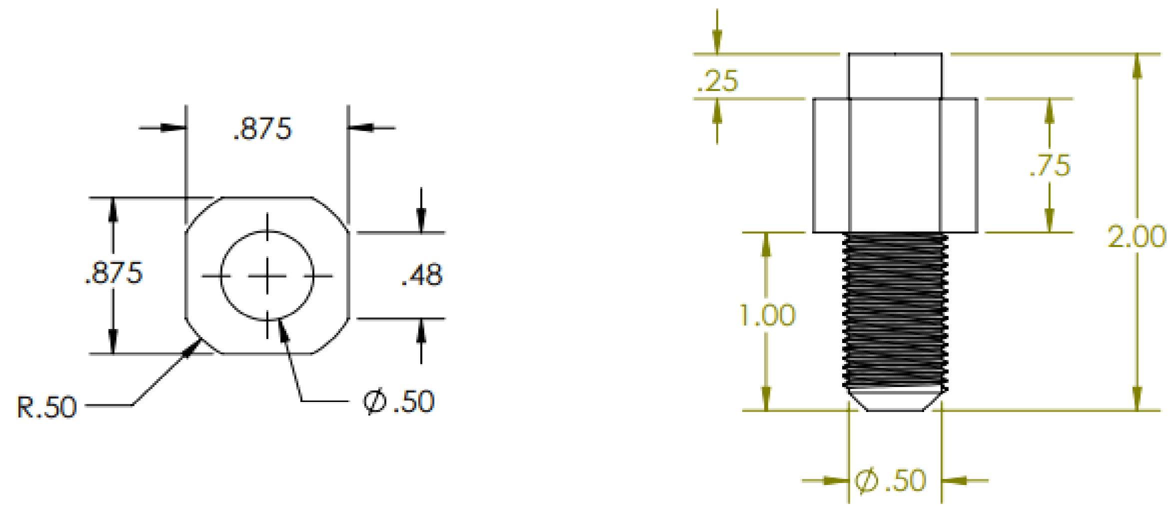
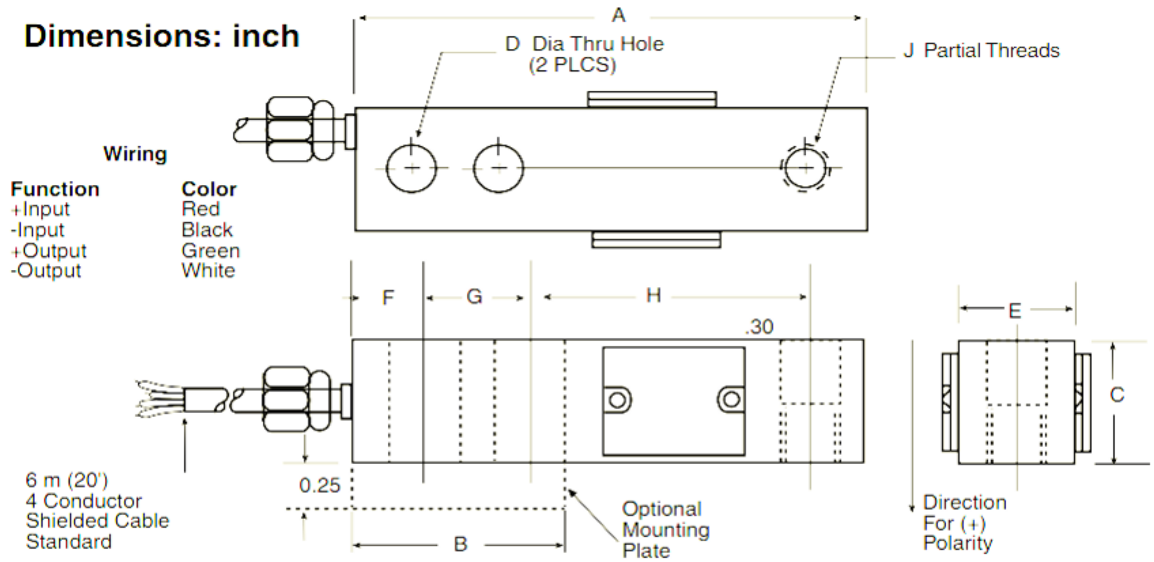


Figure 10 Top View of Top Plate Mount (left). Side View of Top Plate Mount (Right). All numbers are in units of inch

As previously mentioned, at each corner a hole is drilled for the Top Plate to sit on a load cell. A mount is added between the Top Plate and the load cell. The mount is cut out of a 1.0 in diameter steel rod. The Top Plate sits on top (non-threaded side) of the mount, fitting over the 'button' (0.50 inch diameter x 0.25 inch thick, figure 10) and rests on the landing around the button. The space created between the bottom of the Top Plate and the top of the Load Cell is 0.75 in. Around this spacer, four flat surfaces at 90 degrees offset are milled by removing 0.0625 in of the rod, resulting in the width of 0.875 inches between the two opposing sides (figure 10). These flat sides are designed to fit a 7/8 inch open-end wrench in case the mounts become seized to the Load Cells. Due to the original diameter of 1.0 in (radius (R) of 0.59 inch) and the dictation of 0.0625 in removal of material, the 0.48 in flat surface becomes the consequence. The 1/2" – 20 x 1.00" long threads were dictated by the hole in the Load Cells where this mount screws into the Load Cell (reference point J in figure 11).

OMEGA LCJA 1K Shear Beam Load Cell



Capacity	A	B	C	D	E	F	G	H	J
500	5.12	2.25	1.0	.53	1.25	.62	1.0	3.0	½-20
1K-4K	5.12	2.25	1.25	.53	1.25	.62	1.0	3.0	½-20

Figure 11 Omega LCJA dimensions from (Omega, n.d.)

As taken from figure 11, the Load Cell measured 5.12 in x 1.25 in x 1.25 in (length x width x height). Starting from the rear of the load cell (left side of **Error! Reference source not found.**figure 11), the first hole for mounting the Load Cells to the frame below it, measures (centered) at 0.62 in (reference F, figure 11), and the second mounting hole measures (centered) at 1.0 in from the center of the previous hole (figure 11). The holes for mounting the Load Cell to the frame measure 0.53 in in diameter (reference D, figure 11). The distance from the center of the second mounting hole to the frame to the hole for the Top Plate Mount (reference H figure 11) is 3.0 inch. Additionally, all the holes are centered in the middle of the width of the Load Cells.

SPECIFICATIONS
Rated Output: 3 mV/V ±0.0075 mV/V
(actual output supplied with each load cell)
Excitation: 10 Vdc (15 Vdc maximum)
Accuracy: ±0.037% Full Scale
Linearity: ±0.03% FS
Hysteresis: ±0.02% FS
Repeatability: ±0.01% FS
Zero Balance: ±1% FS
Creep In 20 min: ±0.03% FS
Operating Temperature: 0 to 150°F (-18 to 66°C)
Compensated Temperature: 0 to 150°F (-18 to 66°C)
Thermal effects: Zero - 0.0015% FS/°F Span - 0.0008% RDG/°F
Maximum Load: 200% FS
Side Load Rejection: 500:1
Bridge Resistance: 350 Ω nominal
Full Scale Deflection: 0.015 in to 0.025 in
Construction: Nickel Plated Steel
Cable: 20 ft 4-conductor shielded 22-gage wire

Figure 12 Omega LCJA Specifications

Figure 12 is the generic specifications for Omega's line of LCJA load cells. Specifically, the Omega 1000 lbs Shear Beam Load Cells are accurate to ±0.037% of full scale (FS) which is ±0.37 lbs per load cell. This accuracy equates to ±1.48 lbs per scale (four load cells), 2.96 lbs for two scales (eight load cells), and 4.44 lbs for three scales (twelve load cells). The load cells are linear to 0.30 lbs per load cell, or 1.20 lbs per scale, and can compensate for temperature change from 0° F to 150° F.

Load Cell Spacer

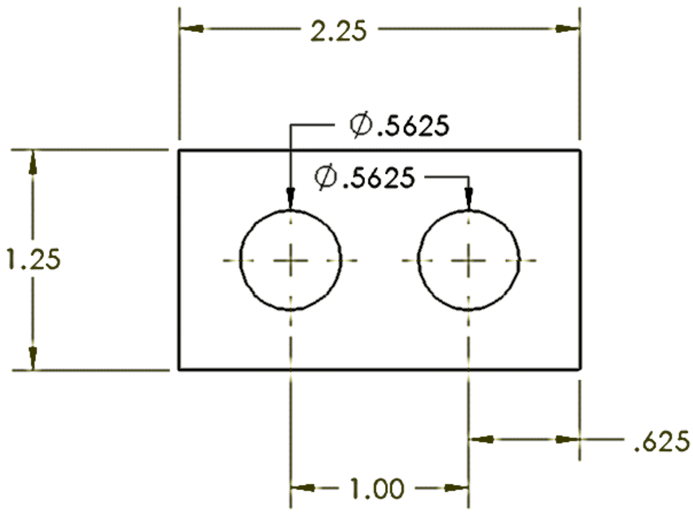


Figure 13 Load Cell Spacer. All numbers are in units of inch. This spacer is built to similar specifications as the spacers sold by Omega.

Between the bottom of the load cells and the frame, a spacer is added. Since the load cell is a beam type load cell, it needs the ability to deflect (particularly downward) without interference from the frame. This spacer is required to give the maximum amount of deflection need for the load cell to be used properly.

The spacers measure 2.25 in x 1.25 in x 0.25 in (length x width x height). Two, 0.5625 in, holes are cut into the spacer at 1.00 in between the centers (figure 13). The holes are 0.625 in from the 1.25 in edge.

To hold the load cells and spacer to the frame of the scale, 1/2" – 13 x 2.25" bolts were inserted into the mounting holes (two per load cell). The bolts were inserted from the frame to the top of the load cell and the 1/2" – 13 nuts tightened down to the top of the load cells.

Walkover Scale Frames

The frames are constructed of the same 0.25 in x 2 in x 2 in angle as the supports on the bottom side of the Top Plates due to cost efficiency of buying in bulk. Four different designs are made with mild steel angle. The four pieces are listed as 1001, 1002, 1003, 1004 (figure 17).

1001 is the most common design among the mild steel angle. These pieces run perpendicular to the movement of cattle. The piece is 36.35 in long. One of the 2.0 in faces has opposing 45 degree cuts at each end, angling inward (figure 14), while the other 2.0-in face has three 0.5625 in holes drilled into it for joining the frames together: one centered at 5.00 in from the end of the angle, the second is centered at 18.125 in from the end, and the third centered at 31.25 in from the same referenced end.

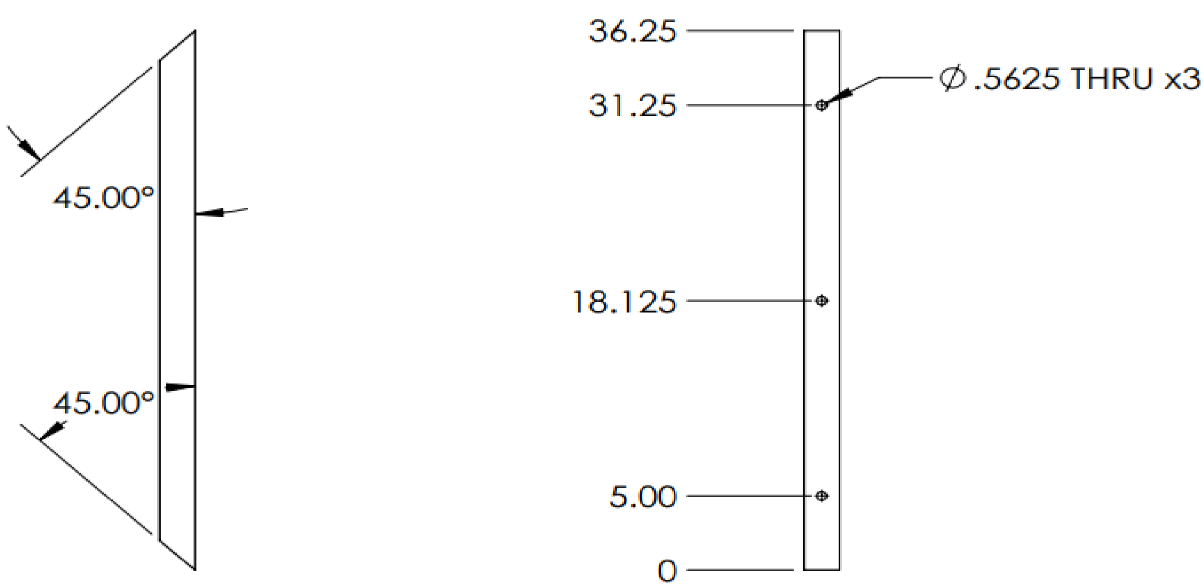


Figure 14 Face 1 of Angle Steel Number 1001 (Left). Face 2 of Angle Steel Number 1001 (Right) All numbers are in units of inch.

All holes are center on the 2.0 in face. Face 1 is in a parallel plane to the Top Plate, while Face 2 sits closer to the ground and is in a perpendicular plate to the Top Plate.

1002 and 1003 have similar designs to them, the only difference between the two is the distance from the edge of the angle to the mounting holes are swapped (figure 15). Similarly, to 1001, 1002 and 1003 angles have opposing 45-degree cuts on one face. 1002 and 1003 are 35.625 in long and the holes are cut on the same face of the as the opposing 45 degree cuts.

1002 has two 0.5625 in holes that are centered 1.00 in apart and the first hole is centered 5.25 in from the left edge of the angle (figure 15). Additionally, two 0.5625 in holes are centered 1.00 in apart; however, the first hole is centered 2.625 in from the right edge.

1003 has two 0.5625 in holes centered 1.00 inches apart and the first hole is centered 2.625 inches from the left edge of the angle iron figure 15). Additionally, two 0.5625 in holes are centered 1.00 inches apart; however, the first hole is centered 5.25 inches from the right edge.

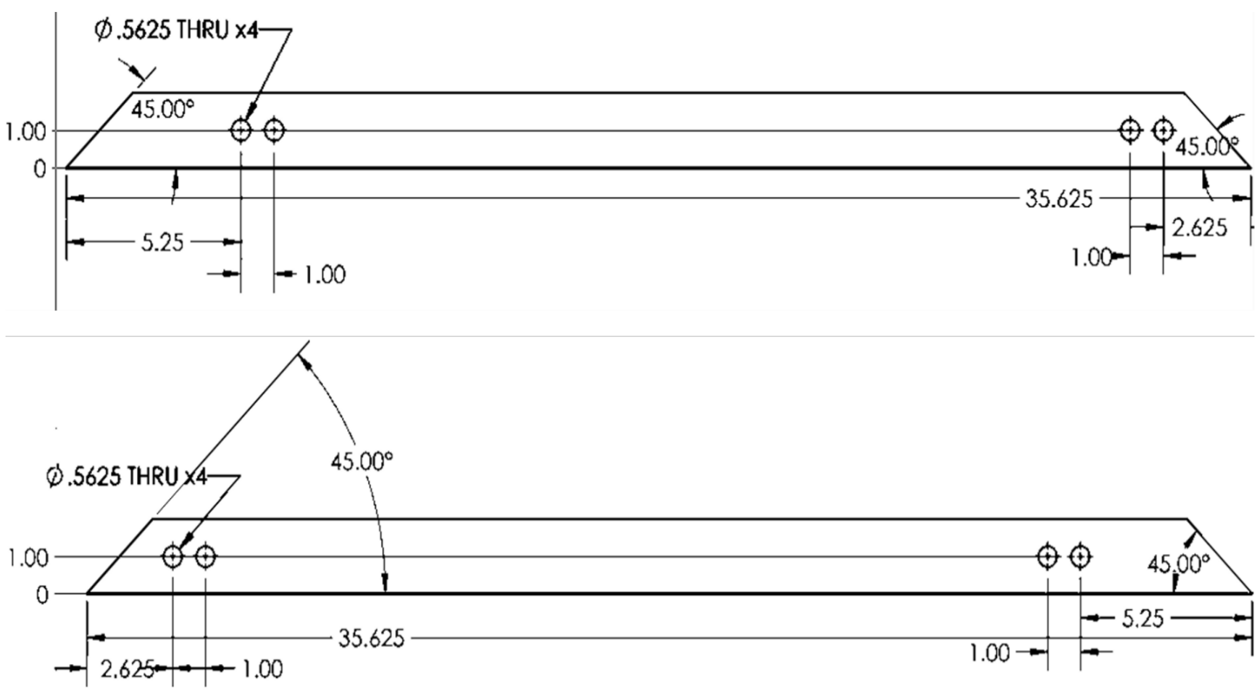


Figure 15 Angle Iron Number 1002 (Top). Angle Iron Number 1003 (Bottom). All numbers are in units of inch.

1004 is 38.25 in long and has opposing 45 degree cuts at either end (figure 16). The holes are cut on the same face as the opposing 45 degree cut. A pair of two 0.5625 in holes are drilled 1.00 in apart. One of the pairs has the first hole centered 5.25 in from the right edge of the angle iron, and a second pair of holes has the first hole drilled on center 5.25 in from the left side of the angle

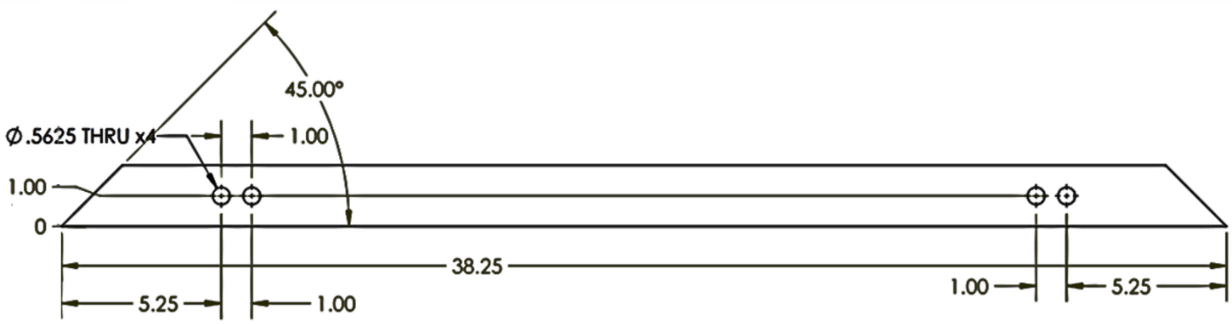


Figure 16 Angle Iron Number 1004 All numbers are in units of inch.

The end scale frame is built from four pieces: 2 x 1001, 1 x 1002, and 1 x 1003 (figure 17). The two 1001 angle iron pieces are on opposing sides of the rectangle, while 1002 and 1003 angle pieces are mirrors of each other (figure 16)

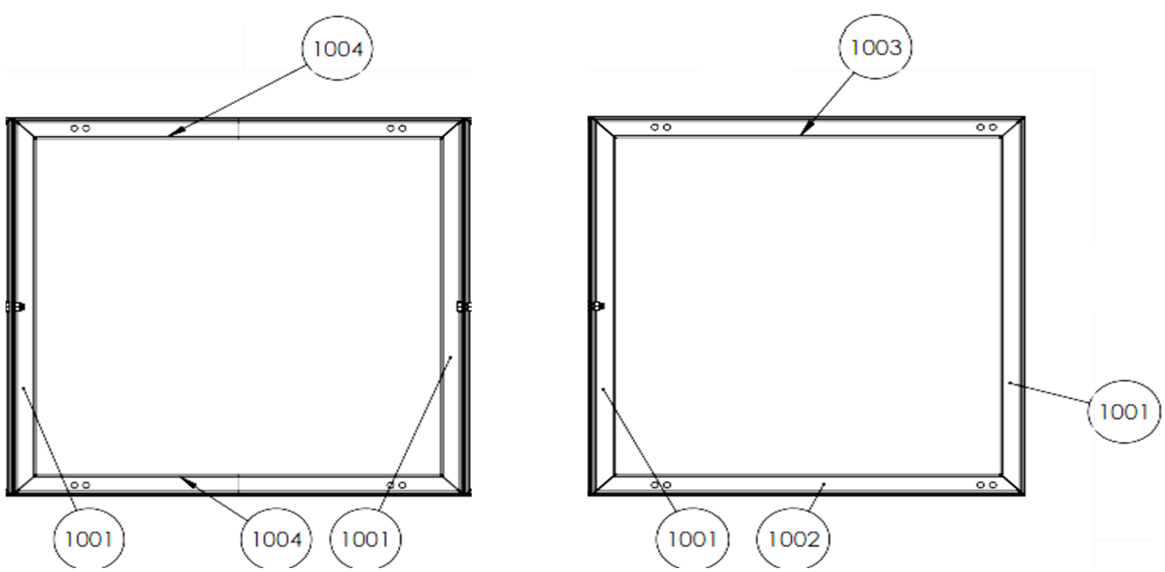


Figure 17 Bottom View of Middle Scale Frame (Left). Bottom View of End Scale Frame (Right)

The middle scale's frame is built from four pieces: 2 x 1001 and 2 x 1004. The two 1001 angle iron pieces are on opposing side of the rectangle, while both 1004 angle pieces are on opposite sides of the rectangle from each other (figure 17).

The frames for the two end scales (figure 18) are mirror images of each other, while the middle scale is different. For each scale frame the edges of the angle where the 45 degree opposing cuts are made, meet together with the other 45 degree opposing cuts from other pieces of angle, and all four pieces make a rectangle. These four pieces are completely welded together at the 45-degree cut interface. Each pair of holes drilled 1.00 in apart are drilled for the mounting bolts, which mount a load cell, a load cell spacer, and frame together. Thus, each scale has four load cells, and the load cells mount orient outwards, as shown in figure 19.

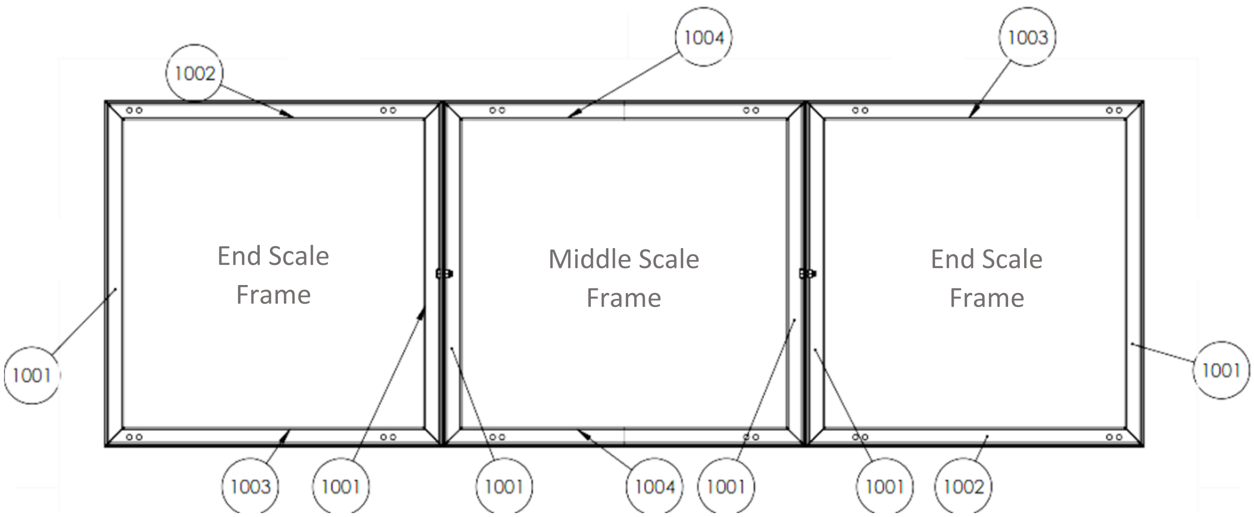


Figure 18 Bottom View of Scale Frames (Two End Scale Frames and a Middle Scale Frame)

Scale Assembly

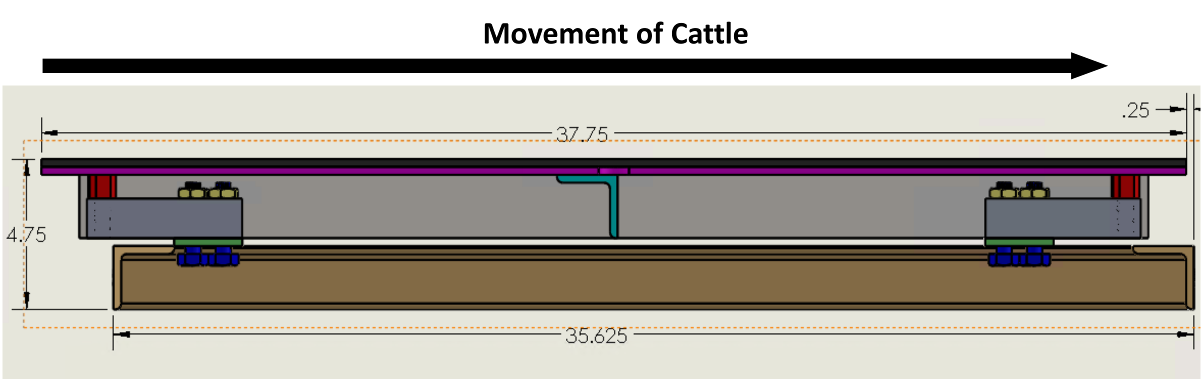


Figure 19 Individually Colored Scale Pieces in Scale Assembly

When all of the individual pieces of the scales are combined together, as seen in figure 19, the scale stands 4.75in tall. 4.75in is the maximum step up height for the animal. Often this height is reduced due to the walkover scales being placed into sand or rock and material placed around the scale platform. Figure 19 is a cross-sectional view of the walkover scales. Starting at the top of figure 19, the colors and their corresponding parts:

Black = Rubber Mats

Magenta = Top Plate

Light Blue = Angled steel part number 1002

Light Grey (behind light blue) = Angled steel part number 1001

Red = Top Plate Mount

Dark Grey = Omega 1000 lbs Capacity Shear Beam Load Cell

Yellow 1/2" – 13 nut

Seafoam green = 0.25 inch spacer

Blue = 1/2" – 13 x 2.25” bolt

Orange = Scale Frames

Multi-Scales

The frames are held together by 1/2" – 13 x 1.25” long bolts placed in the center hole. The 1/2" – 13 nylon locking nuts are tightened until two threads are showing. The maximum distance the Top Plates could spread apart is 0.75 in, while the closest they could come is 0.50 in. Since two threads are showing, the frames are connected but not rigid with each other, and this gives the scales to the ability to move semi-independently of each other without spreading too far apart. Initially, all three of the holes between each of the frames had nuts and bolts through them, and the nuts were tightened down completely, but it was found in testing that when the bolts were tightened against the frames, movement on one scale would affect the weight readings on the adjoining scales.

The two End Scale Frames are for ‘Scale 1’ and ‘Scale 3’ while the Middle Scale Frame is for ‘Scale 2’.

During the course of the study two different setups were tested. One setup utilized all three scales, which is described in this study as 3 Scale Beef Cattle portion of this study, while a second setup utilized only two of the scales (Scale 1 and Scale 2), which is described in this study as 2 Scale Beef Cattle portion. Removing Scale 3 was easier than removing Scale 2 and attaching Scale 1 to Scale 3. The removal of Scale 3 makes Scale 2 an end scale during the 2 scale portion of this study.

Two Walkover Scales

When testing the two-scale setup the overall length is 76.00 in (1.93 m), figure 20. 76.00 inches is slightly longer than the longest dimension (75.50 inches) calculated in the Dimensions section of this chapter. The additional 0.50 inches is the distance between Scale 1 and Scale 2 In this setup the animal moves from left to right across the scales, stepping first up and onto ‘Scale 1’ and second onto and off ‘Scale 2’.

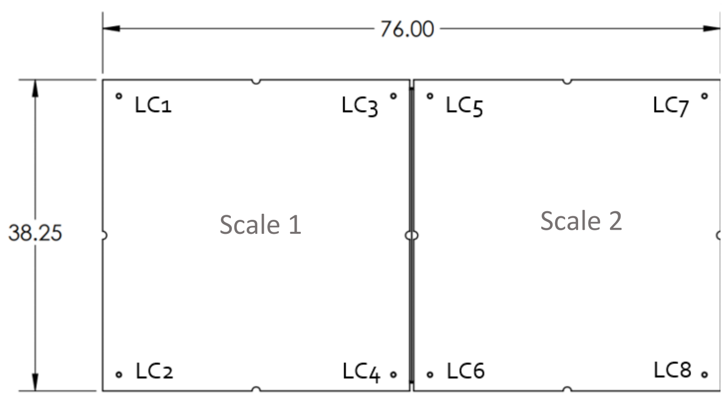


Figure 20 Two Walkover Scales. All numbers are in units of inch.

Each load cell needed to be named for easier identification during the building of the scales, and later data collection and processing. The 2-Scale Beef Cattle portion of this study utilized eight load cells, four load cells for each scale placed at each corner of the scale. Figure 20, shows the labeling for each load cell. Load cell 1 through load cell 4 were apart of Scale 1 while load cell 5 through load cell 8 were apart of Scale 2. “LC1” was used as shorthand to indicate “load cell 1”

Three Walkover Scales

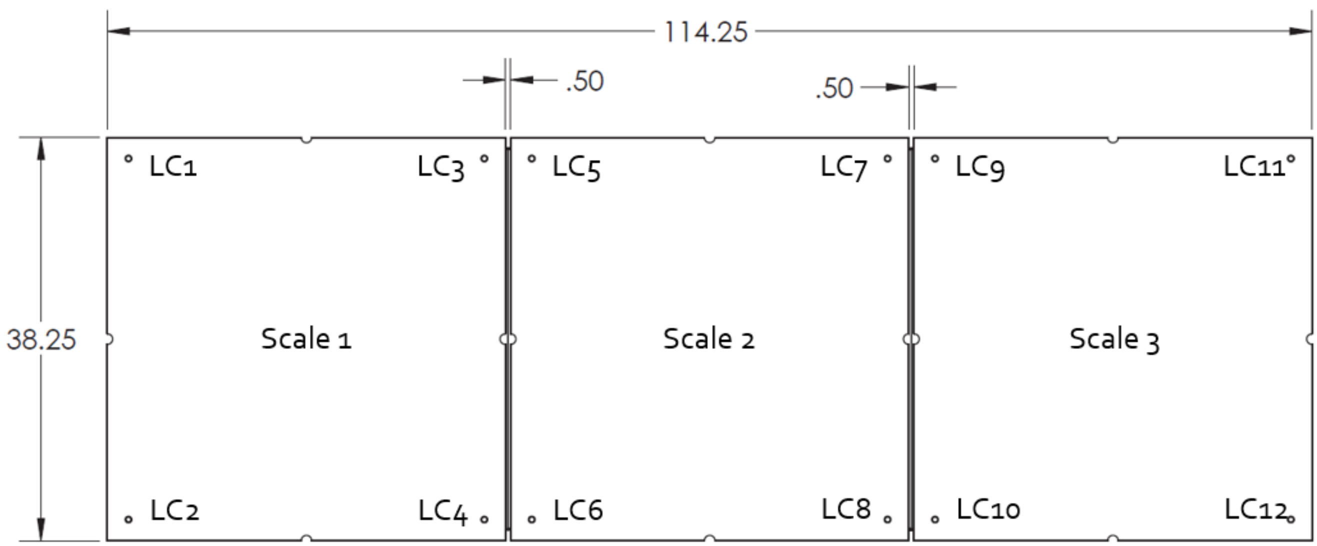


Figure 21 Three Walkover Scales. All numbers are in units of inch.

A series of three individual scales were used as in a portion of this study in an attempt to answer the question “how many scales are needed to accurately predict the static weight of cattle,” and to assist in the separation of cattle data during crowding events, by continuing to collect dynamic weight data of an animal from two adjoining scales (one end scale and the middle scale), even when half of an additional is on the other end scale. As indicated in figure 21, the three scale setups’ overall length was 114.25 in (2.90 m) . 114.25 inches is slightly longer than 1.5 times the longest animal dimension calculated in the dimensions section of this chapter. The longest animal dimension calculated was 75.50 inches, and 1.5 times this dimension is 113.25 inches. The 1.00 inch difference between the longest dimension of the animal and the overall length of the three scales is the two 0.50 inch spacing’s between the scales (figure 21). The scales are numbered according to the movement direction of the animal. The first scale the animal crosses is ‘Scale 1’ while the last scale the animal leaves is ‘Scale 2’.

Thus, following figure 21, the animal moves from left to right across the scales, and the scales are subsequently labeled ‘Scale 1’, ‘Scale 2’, ‘Scale 3’.

Similar to the two scale portion of this study, each of the scales has four load cells under each corner of the scale. Load cells 1 through 4 are used under Scale 1 and load cells 5 through 8 are used under Scale 2. As the name suggests, the three scale portion of the study utilizes a third scale. Scale three again has four load cells under each corner of the Top Plate. These load cells are labeled LC 9 through LC12, where “LC” is shorthand for “load cell”.

Electronic Hardware Setup

There are twelve individual load cells for the 3 scale portion of this study and eight individual load cells for the 2 scale portion of this study. Each corner of a scale has a load cell placed underneath of it. Each of the load cells are labeled “LC1” through “LC12.” “LC1” through “LC4” are incorporated into scale 1, “LC5” through “LC8” are incorporated into scale 2, and “LC9” through “LC12” are incorporated into scale 3. The weight on each load cell is determined by measuring the voltage between the differential signal OUTPUT + and OUTPUT-, as seen in figure 22.

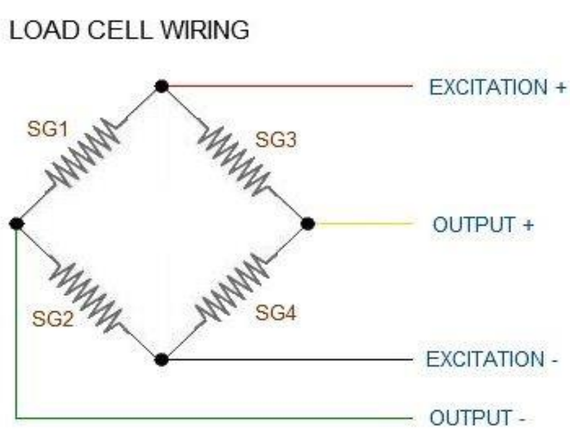


Figure 22 WHEATSTONE BRIDGE (LOAD CELL WIRING)

Each individual load cell is attached via twenty-foot cable to their own Load Cell Amplifier. Each cable contains five conductors: red, black, yellow, green and bare which correspond to excitation (+), excitation (–), output (+), output (-), and shield, respectively. These color wires attach to the color coded (left side) of the Load Cell Amplifier (figure 23). All of the colored wire connect directly to the Load Cell Amplifier, while the bare wire is connected to a true ground connection.

To provide amplification and digital conversion of the load cell signal, a Sparkfun Load Cell Amplifier board HX711 was selected. The HX711 was chosen because of its main function as a 24-bit analog-to-digital converter, which is to measure the voltage difference between the outputs and attribute those to a 24-bit unsigned integer.

The Omega load cells have a ±3mV/V excitation. The HX711 gave a 5V input bringing the excitation range to read of the load cell to ±15 mV. The 24-bits has to accommodate -15 V to + 15V. Since the load cells are only used in one direction for the scales (+15mV), the available resolution for the HX711's is half of the 24-bit unsigned integer, or a 12-bit unsigned integer. The resolution for the HX711 is 3.66 µV per bit, and the resolution for the load cell is 0.25 lbs (1000 lbs / 2^12).

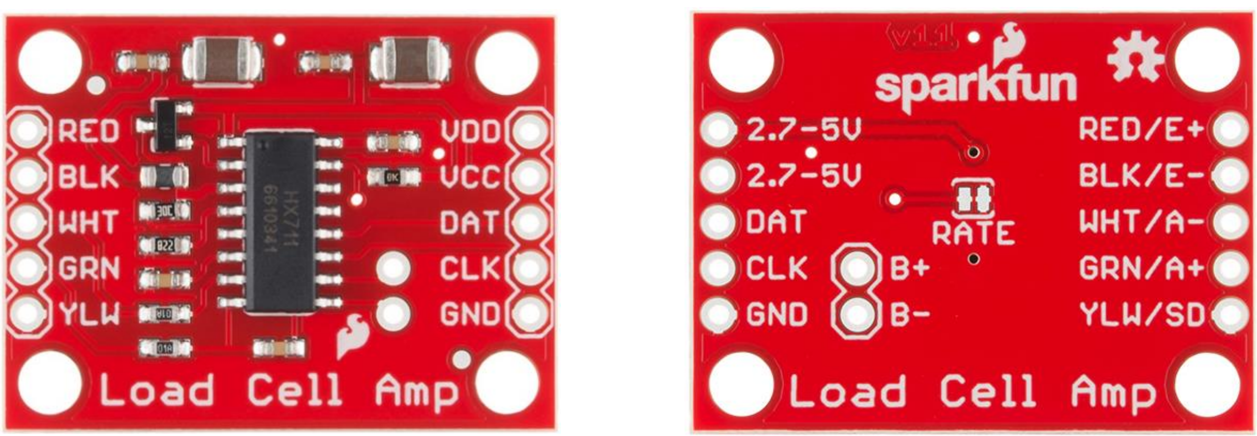


Figure 23 SPARKFUN LOAD CELL AMP: Top Side (LEFT). Bottom side (RIGHT)

To connect the HX711 to the microcontroller, VCC and VDD figure 23 on the right side of the board were connected together and connected via a wire to the 5V pin of the microcontroller, reprinted from *Sparkfun Load Cell Amplifier – HX711* Sparkfun. DAT on the HX711, which is the data output, is connected to pin 4 of the microcontroller. CLK on the HX711, which is the clock output, is connected to pin 2 of the microcontroller. GND on the HX711, which is the ground, is connected to the GND pin on the microcontroller.

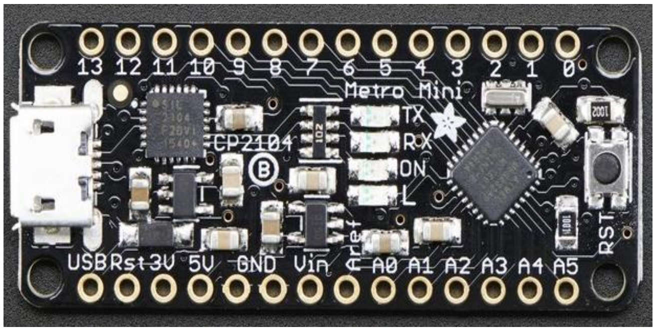


Figure 24 Adafruit Metro Mini 328

The Adafruit Metro Mini 328 microcontroller is an Arduino compatible microcontroller chosen to read the 24-bit unsigned integer of a single HX711. Each of the microcontrollers has a micro USB port (figure 24), which connects to a computer via the USB bus. Figure 24, reprinted from *Adafruit Metro Mini 328 – Arduino – Compatible – 5V 16MHz* Adafruit

Figure 25, illustrates the hardware setup per scale. At each corner of the scale is a load cell. Each load cell is connected to its' own dedicated load cell amplifier. Each amplifier is connected to its' own dedicated Microcontroller (Metro Mini). All of these microcontrollers are connected to a USB Hub.

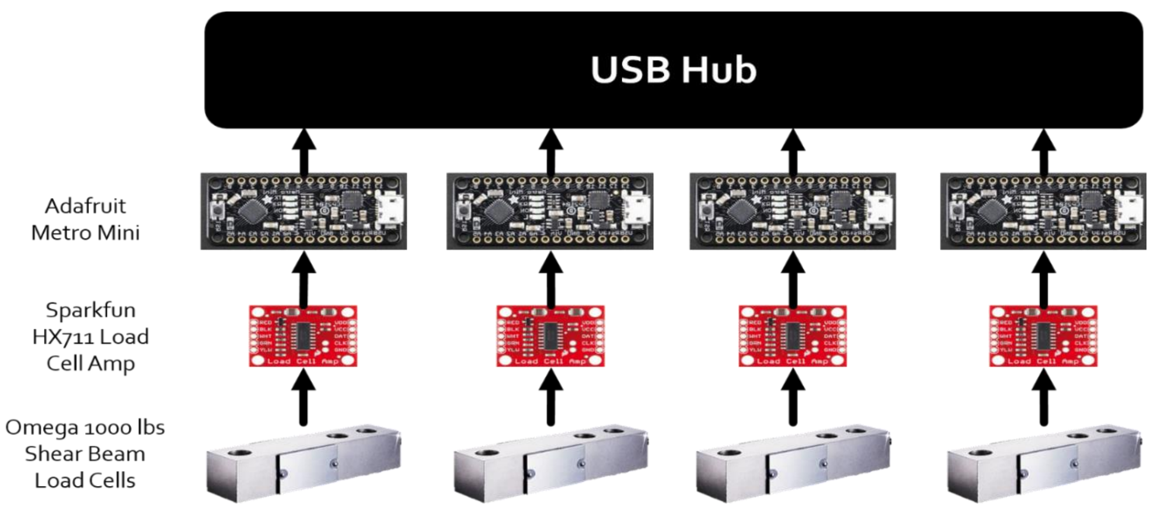


Figure25 Hardware Setup Per Scale

Figure 26 illustrate the hardware used in the 3 scale portion. To understand the hardware setup for the 2 scale portion, remove Scale 3 from the figure 26 and the hardware associated with it. Each scale has a set up four shear beam load cells, connected to their own, load cell amplifiers, connected to their own microcontrollers. All microcontrollers are connected to a USB hub, which is connected to a computer.

A video was taken each time a data collection event occurred, using a Logitech webcam which connects to a computer using the USB port. Each video is overlaid with the current Unix time during data collection. Unix time is the number of seconds elapsed since January 1, 1970. This action was performed to try and determine the exact time when an animal steps onto and off of each scale. The computer used for this study is a Lenovo EDU series Yoga, with Windows 10, Microsoft Office 365, and SQlite3.

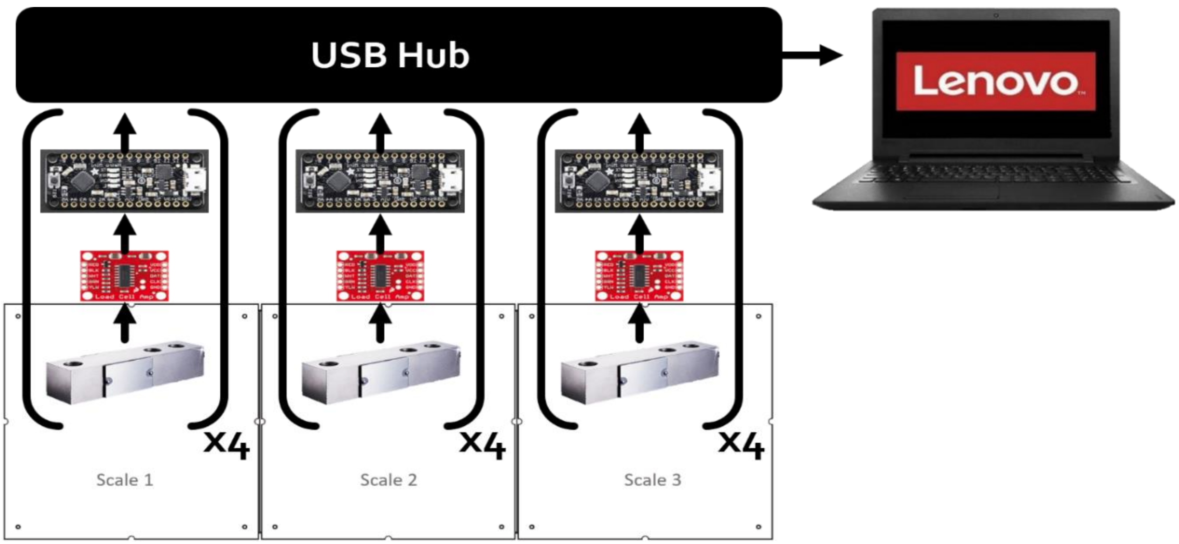


Figure 26 Hardware Setup for 3 Scales

Software Flow

The voltage measured across the two outputs on the Wheatstone bridge of each load cell is converted to a 24-bit unsigned number by the HX711 chip on the Sparkfun Load Cell Amplifier. This number is sent to the microcontroller when polled. The microcontroller uses C++ as its' coding program, and C++ uses 32 bit signed numbers. The load cell amplifier converts the 24-bit unsigned number to a 32-bit signed number internally. Each conversion is then stored as the most up-to-date weight reading. Each microcontroller is set at a baud rate of 9600, which means that each microcontroller can transmit up to 9600 bits per second.

The program found in Appendix B was uploaded to each microcontroller for use in the 2- scale and 3 - scale beef cattle portion of this study. Each calibration factor corresponds to a load cell (ex: "calibration_factor1" corresponds to LC1). All of the calibration factors were commented out (not deleted) except for the calibration factor which corresponded to the load cell which the current microcontroller was connected to. Each calibration factor was used later in the program. The function "scale.set_scale(calibration_factor[corresponding load cell number])" obtains the current weight on the load cell from the HX711 load cell amplifier. A later function "scale.tare()" zeros the scale or shows the current weight reading on the load cell as 0.0 lbs.

Appendix C was uploaded to each microcontroller for data collection during the 3 -scale dairy cattle portion of this study. The program utilizes an Arduino library which came with the Sparkfun Load Cell Amplifier HX711 "HX711.h" (Bodge, n.d.). Specifically, the program utilized the "read" function in the .h file. The specific implementation of this function in the Arduino program is "scale.read" (Appendix C). The "read" function takes in the 24-bit unsigned integer given by the HX711 and converts it to a 32-bit signed integer to be used by the C++ code. This "raw" read was used to build the calibration curves during the data analysis portion of the research. The 2-Scale and 3-Scale Beef Cattle portion of the study used calibration factors and the calibration function which is part of the library that came with the HX711. However, through testing it was found that while morning to afternoon calibrations would still be within the allowable error, 0.37 lbs (Omega, n.d.), of the load cells, day to day analysis showed the scales would not maintain their calibration.

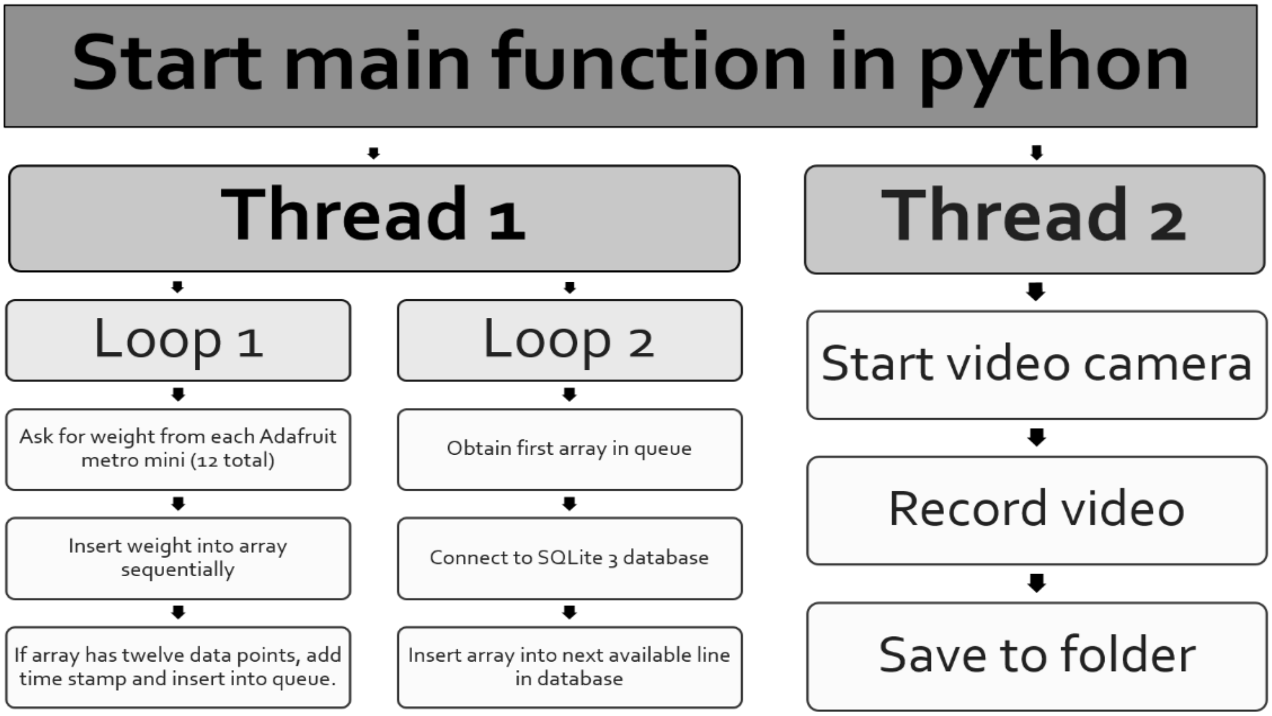


Figure 27 Software Flowchart of Data Acquisition

As illustrated in figure 27, two threads are present during each data collection event. Both threads are contained within the computer and are written in Python. Thread 1 involves data collection and saving, while Thread 2 involves video recording and saving. Thread 1 is a single program which contains two looping functions. The complete Python script for Thread 1 can be found in Appendix B for Beef Cattle and Appendix C for Dairy Cattle. Two software loops, Loop 1 and Loop 2, are running in parallel in Thread 1. Loop 1 polls each Arduino, in order, LC1 through LC8 for 2 scales and LC1 through LC12 for 3 scales, for its' current weight reading. Each reading is placed into an internal array (list) in order of load cell and if all eight (or twelve) load cells were polled properly and a weight reading obtained, then an index value (column , table 1) and current Unix (Epoch) time stamp (column 2, table 1) is inserted into the beginning of the array, and the whole array is inserted into a queue. Index values are used to keep python from processing duplicate arrays. Epoch time is number of seconds since January 1, 1970. Epoch time was measured to the one-hundredth of a second, and used to compare against video recordings of walkover data during data processing.

Loop 2 runs the program from inside of Thread 1 (Appendix D). Loop 2 grabs the next available array from the queue and inserts the array into a sqlite3 database for saving. Table 1, illustrates the data arrays obtained from the load cells for the 2 – Scale Beef Cattle portion of this study.

Index	Time_Epoch	LC1	LC2	LC3	LC4	LC5	LC6	LC7	LC8
1	1531741477.67		0.07	0.04	-0.03	0.01	0.03	-0.01	0.02
2	1531741477.67	0.06	-0.05	0.02	-0.01	-0.01	0.01	-0.01	0.04
3	1531741477.68	0.05	-0.02	-0.02	0.05	0	0.01	0.01	0
4	1531741477.68	-0.07	0.06	0.01	-0.01	0.01	0.01	0.01	0
5	1531741477.69	0	0.04	0	-0.05	0	0	0	0.03

Table 1: 2 – Scale Beef Cattle excel table exmple.

Table 1 shows the first five arrays from data set "Tag_181500_20180716_064435". Each row in table 1 is an individual data array. The numbers under "LC[load cell number}" is the weight on the load cell after the HX711 has tared the load cell. All of these values under "LC" are in units of pounds (lbs). The 3 – Scale Beef Cattle portion of this study is the same as the table 1 with four more columns added after "LC8". One column for each of the load cells in Scale 3 (LC9 through LC12). The 3 – Scale Dairy Cattle portion of this study saves 32-bit integers instead of tared weight (top table, figure 31).

Each software loop, illustrated in figure 27, repeats until the operator of the walkover scales presses "CTRL+C". This kills Loop 1 and places a "STOP" in the data collection queue. Loop 2 will process all of the data arrays in the data collection queue until this "STOP" insert occurs.

Thread 2 (Appendix E) records a video of the data collection using a Logitech webcam. Each frame in the video is overlaid with the current Unix time and saved in a file for later use in data processing. Thread 2 runs until "CTRL+C" is pressed by the walkover scale operator.

Calibration and Preliminary Data

Three distinct data collection events occurred in this study; 2 – Scale Beef Cattle, 3 – Scale Beef Cattle, 3 – Scale Dairy Cattle. The 2 – Scale Beef Cattle and 3 – Scale Beef Cattle data collection events occurred in the summer of 2018, and the 3 – Scale Dairy Cattle data collection event occurred in January of 2019. Forty-six data sets were obtained during the 2 – Scale Beef Cattle data collection event, and thirty eight data sets were obtained for 3 – Scale Beef Cattle data collection event. Only, twenty seven data sets were collected during the 3 – Scale Dairy Cattle data collection events.

Load Cell Calibration for 2 – Scale and 3 – Scale Beef Cattle

Figure 28 498 lbs Cotton Gin Weight and Platform (LEFT). Calibration Platform (RIGHT)

Validation of the scales began in the lab setting. The Arduino script from Appendix A was uploaded to each microcontroller to obtain the calibration factor from each load cell. A platform was built to screw into each load cell individually for calibration purposes (figure 28). This platform measured twelve inch by twelve inch and weighed 10.0 lbs. Each load cell was calibrated using the 498 lbs cotton gin weight on the 10 lbs calibration platform. The calibration factor was moved up or down, until the output read 508 lbs (498 lbs + 10 lbs). This gave the most accurate calibration factor possible for these load cells. As the weight increased the calibration output weight became more sensitive to the calibration factor. These calibration factors were then recorded and used in the Arduino script found in

Appendix B. Each load cell had a unique calibration factor found in Appendix B. For example "calibration_factor1" in Appendix B is the calibration factor for load cell 1 (LC1).

Load Cell Calibration for Dairy Cattle

When this study was unable to predict the static weight of the animal, more lab setting data collection occurred. These weights were used to calibrate the load cells in the morning and afternoon overall several days to check for consistency in load cell calibration factors. This is not to say that the Beef Cattle portions of the study were out of calibration during testing, but that when the calibration of scales was checked before testing with dairy cattle, the load cells would not maintain their calibration. The time between the Beef Cattle testing and Dairy Cattle testing was six months.

Upon analyzing the data from the lab it was found that between morning and afternoon scales calibration would not change much, but between days the load cells would not maintain their calibration. This lack of calibration consistency encouraged the study to attempt more data collection, this time with dairy cattle. For this portion of the study, described in this study as 3-Scale Dairy Cattle, calibration of each load cell was performed in the field directly before testing. Since calibration for the 3-Scale Dairy Cattle portion of this study was performed in the field, two 71 lbs front end tractor weights were used for calibration, instead of the 498 lbs cotton gin weight. The front end tractor weights were easier to handle by operators than the cotton gin weight.

During field testing each load cell is calibrated individually using the afore mentioned twelve inch by twelve inch calibration platform and two 71 lbs front end tractor weights. After each of the twelve scales were individually calibrated, the large multi-cell platforms were placed on the load cells and the data collection was started. After at least ten seconds, the first tractor weight was added and another weight was added after ten seconds. After waiting another ten seconds, one tractor weight was removed, and finally the last tractor weight was removed after waiting another ten seconds. Thus in the data collection yielded a step function of both increasing and decreasing values.

A Linear Calibration curve was built for each of the load cells. This curve was performed by averaging the 32-bit signed integer values from each individual Arduino associated with each known weight placed on the load cell. As seen in figure 29, 0.0 lbs corresponds to a low ADC value, as known

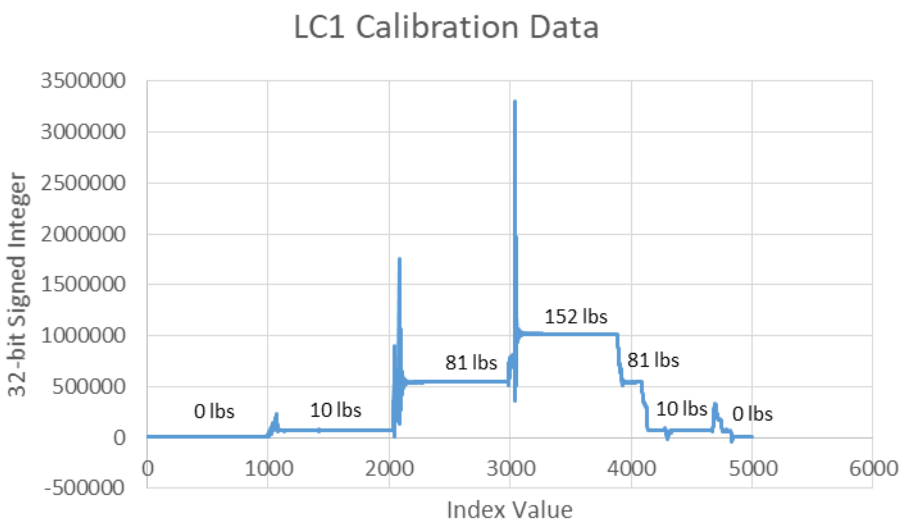


Figure 29 LC1 Calibration Data

weight is added to the load cell and given ten seconds to stop oscillating, each weight creates a plateau or step in the graph. The Linear Calibration curve is obtained by first averaging the ADC values of each step, then using the "LINEST(known_y's,known_x's)" (Microsoft(a)) function from excel which when

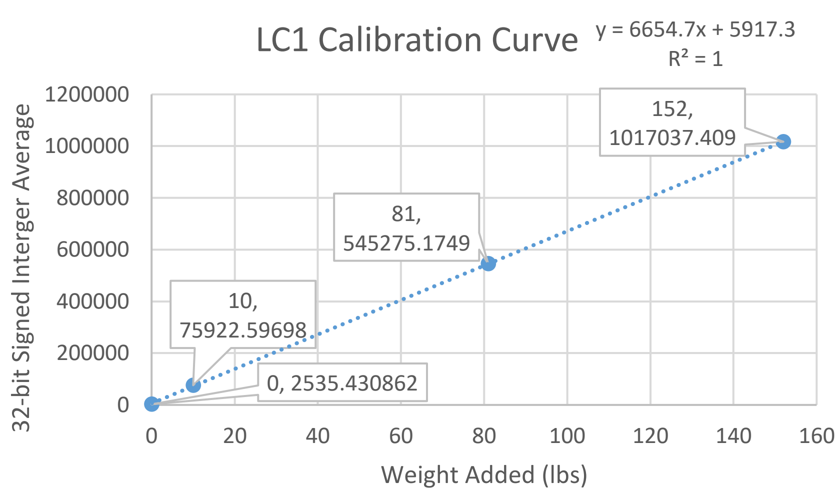


Figure 30 LC1 Calibration Curve

given the known weight placed on the load cells gives the slope for a "Trend line." Second, the

“TREND(known_y’s,known_x’s)” (Microsoft(b)) function in excel is used to obtain the y-intercept for a “Line of best fit curve.” In figure 30, at the top right of the figure, the Trend line is given for load cell 1. Each load cell followed this process to obtain an individual Linear Calibration curve. Each Calibration Curve had the basic format of:

32-bit signed integer = LINEST * Weight + TREND (13)

To convert the 32-bit values obtained during each animals’ weight collection, the afore mentioned Linear Calibration curve is used. Since weight is the desired piece, the Linear Calibration curve had to be adjusted to solve for Weight. The new formula used to convert the data had the basic format:

Weight = (32-bit signed integer – TREND) / LINEST (14)

The conversion from the 32-bit signed integer to the weight value is shown in figure 31. The top table in figure 31, is an example of the 32-bit signed integers in excel, and the center table is the calculated weight values from the equation 14.

Index	Time Epoch	LC1	LC2	LC3	LC4	LC5	LC6	LC7	LC8	LC9	LC10	LC11	LC12
1	1549405434.00		306295	264607	208519	101280	420465	428235	83115	109833	382282	361976	112365
2	1549405434.00	234734	306546	264927	208719	101476	419958	428178	82907	109222	382089	361749	112181
3	1549405434.00	234587	306615	264471	208709	101377	420048	428194	83287	109553	382317	360810	112169
4	1549405434.00	234704	306359	264565	208494	101275	420509	428160	83207	109980	382195	360588	112281
5	1549405434.00	234761	306549	265128	208715	101204	419950	428258	82883	109355	382189	360810	112091

32-bit Numbers From HX711

After Calibration Conversion

LC1_lbs	LC2_lbs	LC3_lbs	LC4_lbs	LC5_lbs	LC6_lbs	LC7_lbs	LC8_lbs	LC9_lbs	LC10_lbs	LC11_lbs	LC12_lbs
-0.89	43.93	43.81	33.06	13.56	62.61	63.48	14.34	20.08	59.27	56.83	18.17
34.38	43.96	43.86	33.09	13.59	62.53	63.47	14.30	19.98	59.24	56.79	18.14
34.36	43.97	43.79	33.09	13.58	62.55	63.47	14.37	20.03	59.28	56.65	18.14
34.38	43.93	43.80	33.06	13.56	62.62	63.47	14.35	20.10	59.26	56.62	18.16
34.39	43.96	43.90	33.09	13.55	62.53	63.48	14.30	20.00	59.25	56.65	18.13

After Zeroing (Taring)

LC1_lbs	LC2_lbs	LC3_lbs	LC4_lbs	LC5_lbs	LC6_lbs	LC7_lbs	LC8_lbs	LC9_lbs	LC10_lbs	LC11_lbs	LC12_lbs
35.27	0.04	0.03	0.02	0.00	-0.05	-0.01	0.00	-0.04	-0.01	-0.08	-0.04
-0.01	0.00	-0.02	-0.01	-0.04	0.03	0.00	0.04	0.06	0.02	-0.05	-0.01
0.02	-0.02	0.06	-0.01	-0.02	0.02	0.00	-0.03	0.02	-0.01	0.12	-0.01
0.00	0.02	0.05	0.02	0.00	-0.05	0.00	-0.01	-0.06	0.00	0.17	-0.03
-0.01	-0.01	-0.05	-0.01	0.01	0.04	-0.02	0.04	0.05	0.00	0.15	0.00

Figure 31: 3 – scale Dairy Cattle excel table exmple.

Preliminary Data / Center of Mass Calculations

Preliminary data were also gathered for a center of mass proportion study. Calculating the center of mass for both the front and back half of the animal, gives the approximate location for either half. This approximate location could be used to track an animal through the multi-scale walkover platform. Additionally, calculating center of mass could allow for lameness detection in cattle. As the animal transfers weight from one side of their body to the other, the center of mass should move from side to side along the y-axis (figure 32). If the animal is consistently favoring one side of the scale and spends more time on one side of the scale (either side of the body), then there is a potential lameness issue with the animal.

To determine the accuracy of each scale to predict the center of mass of an object a cotton gin weight was placed on the scale and measurements from two Top Plate edges to the center of the weight were determined. For the preliminary study, the edge in line with the even numbered load cells (ex. Scale 1, LC2 and LC4) would be considered the positive x-axis and the edge in line with the lowest numbered load cells (ex. Scale 1, LC1 and LC2) would be considered the positive y-axis. Additionally, (x,y) coordinates for each load cells were determined using these edges of the Top Plate. Obtaining the center of mass requires, again, making an (x,y) coordinate from the data.

The X distance for center of mass (COM) approximation comes from equation 15:

$$X = E - (E - F) * (G / H) \quad (15)$$

E = Average X coordinate of two Highest numbered load cells (in)

F = Average X coordinate of two Lowest numbered load cells (in)

G = Summed Data of the two Lowest numbered load cells (lbs)

H = Summed Data of All load cells (lbs)

The Y-distance for center of mass (COM) approximation comes from equation 16:

$$Y = I - (I - J) * (K / L) \quad (16)$$

I = Average Y coordinate of Odd numbered load cells

J = Average Y coordinate of Even numbered load cells

K = Summed Data of Even numbered load cells

L = Summed Data of All load cells

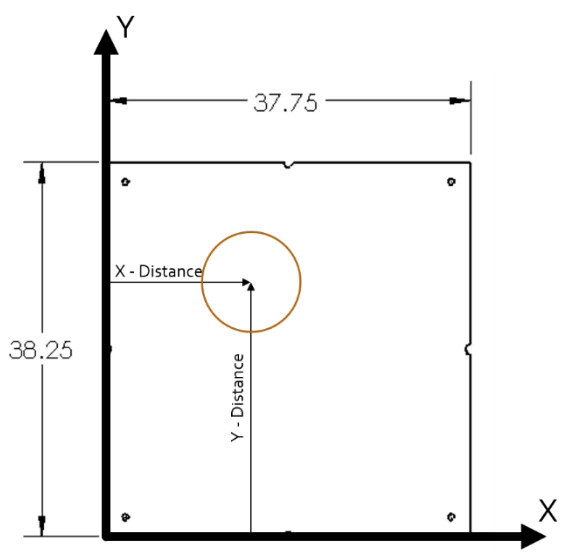


Figure 32 Center of Mass coordinate plane.

A 295 pound cotton gin weight was placed near each of the twelve load cells and measured with a tape to the center of the weight for the actual (x,y) coordinate. Data was collected for each of the load cells, then the (x, y) coordinate was calculated using equation 13 for the x coordinate and equation 14 for the y coordinate. The calculated coordinates were compared to the measured coordinates for accuracy.

Sampling Process Design

Due to the HX711 construction, the sample rate per second (SPS) can be set to either 10 Hz or 80 Hz ("24-Bit Analog-to-Digital Converter (ADC) for Weigh Scales," n.d.). The factory sampling rate is set at 10 Hz, while changing to 80 Hz requires one to cut a connection on the bottom side of the HX711 board. A 10 Hz rate yields a data point every 100 ms, while an 80 Hz rate yields a data point every 12.5 ms. Long, et al. (1991a) indicated that a sampling rate of 50 ms (20 Hz) was sufficient for their study, therefore it is determined that the HX711 must sample at the 80 Hz to satisfy previous literatures assertions on sampling rates for walkover scale systems.

Beef Cattle Data Collection

Data collection in the summer of 2018 was performed at the Pure Bred Beef Center at Oklahoma State University. Specifically, at their wheat pasture barn headed by Dr. Ryan Reuter of the Animal Science department. This place was chosen for several reasons; one, the barn already had a digital static scale which could measure the static weight of the animal for direct comparison with predicted weights from the multi-scale walkover platform, two, the barn had a working system for the cattle, and three the adjacent pastures had beef cattle could be used for this study.

Calibration of the load cells were checked on site before each of the day of data collections for both beef cattle portions of this study. The calibrations were checked using multiple 50 lbs weights, and each individual scale in the multi-scale walkover platform and the static scale were within one pound of each other.

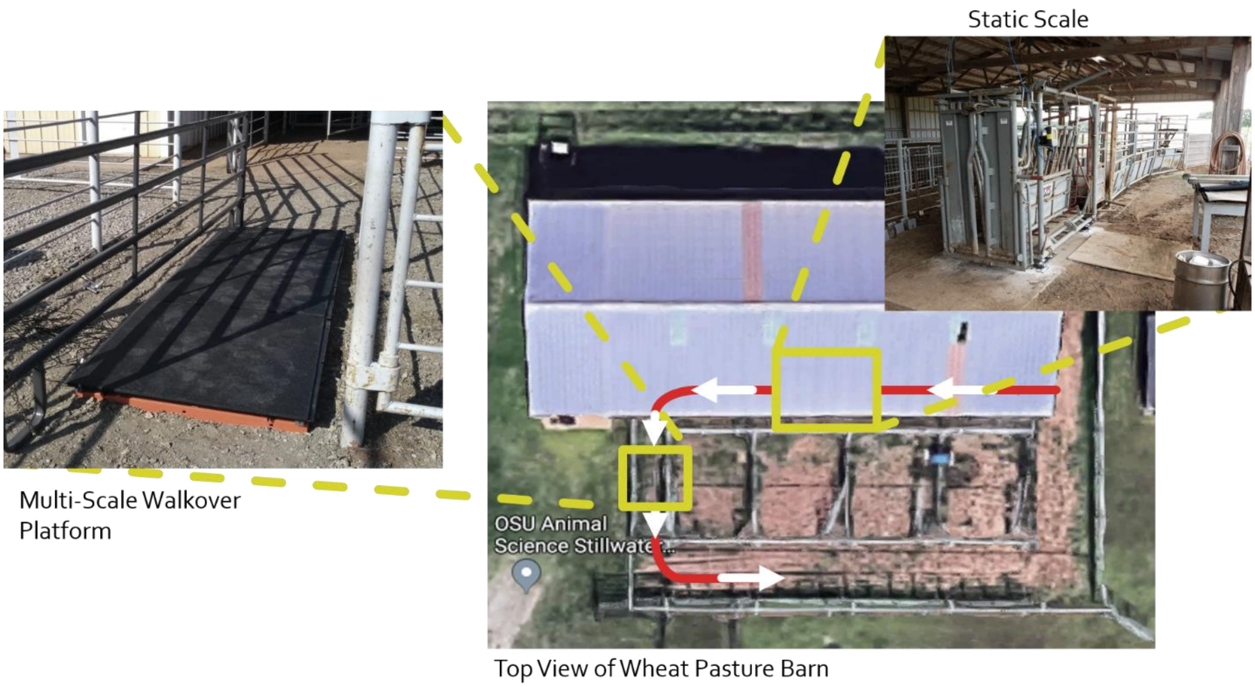


Figure 33 Beef Cattle Data Collection Diagram

The cattle were taken, approximately seven at a time and fed into a single file snaking chute system. Each animal was individually caught in the static scale (figure 33), which doubled as a squeeze chute. The squeeze chute, provided steady measurement for the scale, because some cattle had a tendency to thrash when stopped on the static scales. Each animal had their EID tag read by a EID reading wand, and their other visible tag number was called out. The visible tag number was placed into the file title for the walkover scales data collection software. The animal was let out of the squeeze chute and walked approximately fifteen feet to the walkover scale. This space between the scales was given in an attempt to let the animal calm down (if need be) before the walkover scale platform. When the animal was let out of the squeeze chute the data collection software for the walkover scales was initiated by an operator. The generic formula for the each data collection name was "Tag_[Tag number]_[Current Date(year month day)]_[Current Time (hour minute second)]" as seen in the title in figure 35. When the operator "turned on" or began the data collection set, each load cell weight reading was recorded approximately every 0.0125 seconds (80 Hz). The data collection began as the animal was let out of the squeeze chute (off the static scale) and allowed to freely walk over the walkover scales until all four of the animal's feet had touched the dirt past the end of the scale (figure 33). This animal touching the ground was determined by the site of the operator of the multi-scale platform. The software was then allowed time to finish storing the data into an sqlite3 database, as described in the software flow section of this chapter, before releasing the next animal. This process was repeated for every animal.

Cattle went through the three scale setup twice with a five-day period between tests. When testing the two scale system, cattle went through the system three times on the same day, approximately twenty minutes apart from each other, but testing was only a single day. All of the testing sessions occurred in the morning hours before 10 o'clock. Testing in the morning avoids heat stressing the cattle by putting them through a chute system before the weather got into heat stress conditions.

During the 3 - Scale Beef Cattle data collection the static weight of the animals ranged from 432 lbs to 696 lbs, with a mean (average) of 566 lbs. The same beef cattle were used in the 2 – Scale Beef Cattle data collection and the 2 – Scale Beef Cattle portion of the study occurred roughly two weeks after the 3 – Scale Beef Cattle portion of the study. The cattle in the 2 – Scale Beef Cattle data collection sets had a static weight ranging from 467 lbs to 710 lbs, with a mean (average) of 583 lbs.

Dairy Cattle Data Collection

Once it was determined that each of the load cells individually and all three of the walkover scales provided a linear calibration curve, weight collection of the individual animals commenced. Haltered cattle were led onto the 3 scale platform. The cattle were haltered because it was hypothesized that haltered cattle could be controlled better than non-faltered cattle, and that a more consistent and steady pace over the walkover scales would occur. At the beginning of each data set, static weight of the animal is attempted by making the animal stand on the scales for twenty seconds (figure 34). The first ten seconds, the front half of the animals would stand on the second scale and the back half of the animal would stand on the first scale (left picture in figure 34). The second ten second, the front half of the animal would stand on scale three and the back half of the animal would stand on scale 2 (right picture in figure 34). During the data analysis portion of this study, the last five seconds of the ten second standing time was averaged to compare against the predicted static weights from the dynamic walkover weights. Using the last five seconds assisted this study in avoiding averaging oscillating data from the scales when the animal moved onto them. During initial calibration of load cells, it was found that waiting ten seconds was necessary because oscillations (large changes in data readings) occurred when after weight was placed on the calibration platform. Additionally, scale-to-scale consistency was calculated to determine if any scale bias occurred. After completing both static weight collections, and in the same data file, the cow was led back around the whole of the multi-scale system and each cow walked over the scales multiple times to obtain their dynamic weight data sets.

Figure 34 Dairy Cattle Static Weight collection. LEFT First ten seconds. RIGHT second ten seconds.

Post processing of the data collected reveled a maximum static weight of dairy cattle to be 1662.07 lbs and a minimum static weight to be 1001.58 lbs.

Data Preprocessing

Data analysis began by converting the saved data in the sqlite3 database to Comma Separated Variable (CSV) files. The database browser provided by SQLite has a built in function for this conversion ("DB Browser for SQLite," 2007). This built in function converts each file independently to its own CSV file. Each file was then copied to an excel workbook as individual worksheets.

Beef Cattle Data

Since the beef cattle data was already converted to pounds, no calibration curve, or manipulation in that manner is necessary. Due to the semi-erratic behavior of the data which occurs from the constant movement of the animal over the scales, a 10 point moving average was calculated for each of the scale combinations (Scale 1, Scale 2, Scale 3, Scale 1+2, Scale 2+3, Scale 1+3, Scale 1+2+3). As seen in figure 35, the initial data collected during testing (blue line) being 'choppier' or more erratic than the moving average data (orange line), which is smoother and provides more consistent results between data sets.

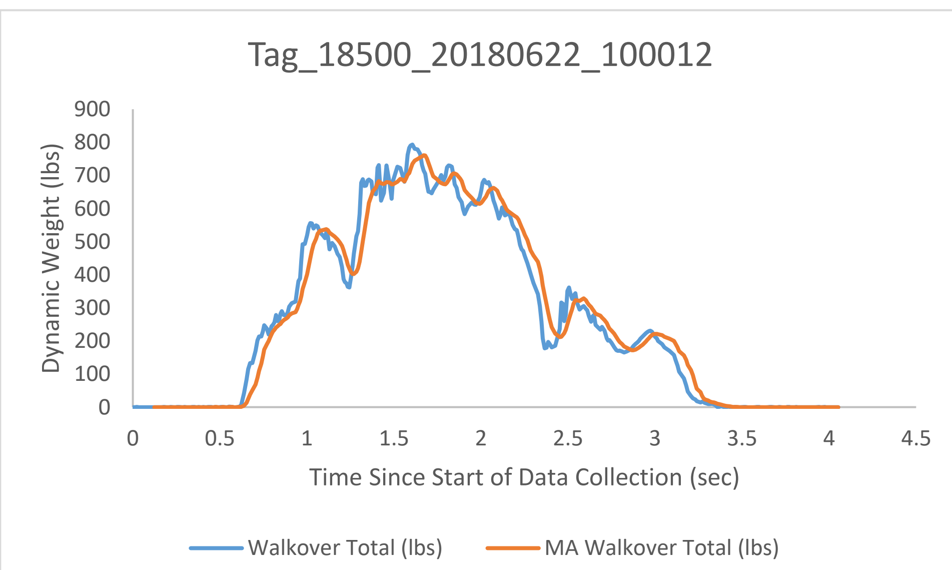


Figure 35 Dynamic Walkover Data Tag 18500

All subsequent beef cattle data analysis (except FFT analysis) was performed on this smoothed data.

Dairy Cattle Data

A VBA script was created to convert each of the 32-bit signed integers collected from each load cell during the animal weighing process, using the formula above. The new numbers were inserted thirteen columns to the right of the original data, as to not discard the original data. These new numbers provided true weight placed on each load cell during testing. However, the weight of the plate and livestock mats were not of any use, therefore the first one hundred data points of each individual load cell was averaged together for each data set, to give the offset factor. The offset factor is used in the "Taring" of any scale. Each data point was again converted, or adjusted, down based on the offset for each load cell. These new adjusted numbers were placed thirty-nine columns to the right of the original 32-bit signed integer. These new numbers are now the weight on the load cells after removing the weight of the scale and livestock mats.

A video was taken during each of the data collections. The video was overlaid with the current epoch time during data collection. The time from the start of the video and the beginning of static and dynamic weight collections is determined using simple subtraction, observed start time of each collection minus the beginning time of the video. The time difference calculated from the videos are

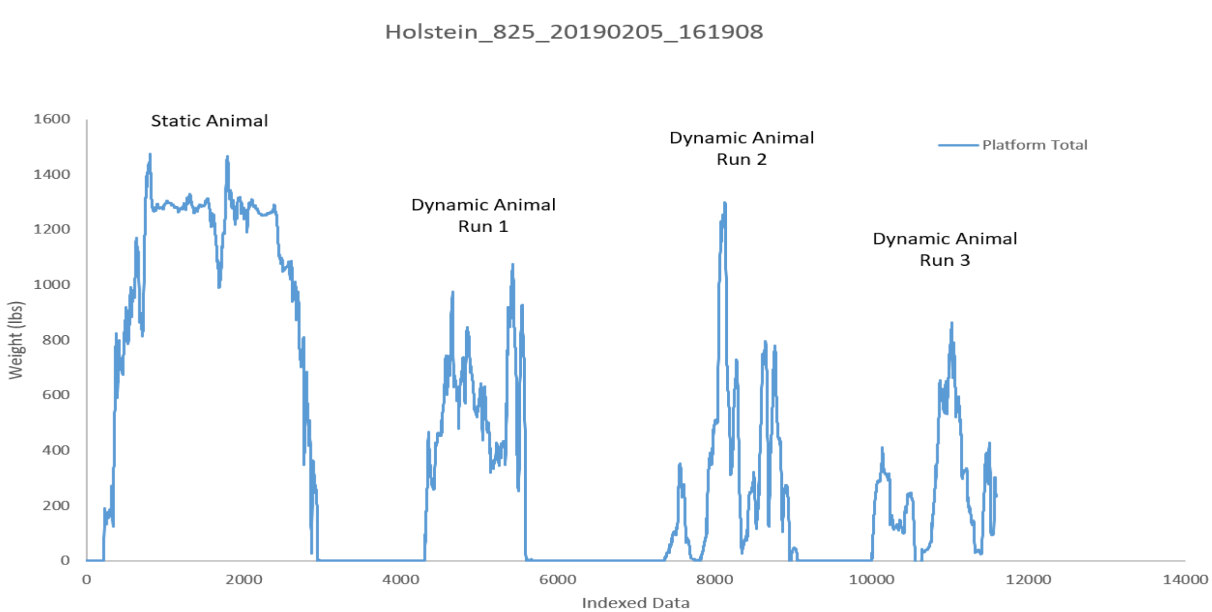


Figure 36 Holstein 825 Complete Data Set

compared against the time stamps in the data set in an effort to find the approximate starting row for each of the data sets (static and walkovers). The starting point and ending point for each run is determined through observation of a graphed plot (figure 36). Index is used for the x axis of these graphs and not time because for an unknown reason the python program saved the epoch time in the database as time rounded to the whole second, as opposed to before where the time was saved down to the millisecond. Comparing the indexed value and the adjacent time saved in the excel file to the time in the video gave us the approximate time each run began. The "Static Animal" occurs when the animal is stationary on the scale. Approximately twenty seconds at the beginning of each data collection set, the cow is stationary. The first ten seconds, the animal is standing with the front hooves on Scale 2 and the back hooves are standing on Scale 1 (Left side, figure 34). Then after ten seconds, the animal is moved forward to the point where the front hooves are standing on scale 3 and the back hooves are standing on scale 2 (right side, figure 34). Again, the animal is stationary for ten seconds. Ten seconds of standing was chosen because during load cell calibration, the load cell would oscillate for five seconds and not provide a steady output of data. After approximately five seconds of oscillation, the load cell output would provide a stead data output. This same principal was applied to cattle on the scale during static weighing's. "Dynamic Animal Runs" occur when the animal is led across the scales.

Once the static data range and the dynamic data range is determined, each data range is copied and pasted into its' own excel worksheet, in the same format as the 3 scale beef cattle study. This separation of data allows for easier data analysis through VBA applications. As seen in figure 36, there is a period of a semi-static state for the cow, and three distinct walkover data sets.

Data Analysis Methods

Successive Increase/Decrease in Data Values Analysis Method

Peiper et al 1993 indicated in their study that the beginning of their data array for averaging began when there were consecutive increases in data outputs from their walkover scales. The study also indicated that their decision to stop input into the data array occurred when five consecutive decreases in data outputs. A similar method was applied to the moving average data sets. Peiper et al. 1993 used the letter "M" as their variable to keep track of the number of decreasing data outputs. This study utilized the letter 'M" to maintain some continuity during analysis between the two studies. Various "M" values, or "m thresholds" were tested. As seen in figure 37, back to back data points were compared against each other. If the second data point was greater than the first data point, this was considered an increasing data points. If an M number of successively increasing data points occurred, a data averaging array was started. Again, back to back data points were compared against each other. If data point two was less than data point one, this was considered a decreasing data value. If an M number of comparisons occurred successively, the data was quit being added to the data averaging array. All data points in this data averaging array were averaged together, and this average was considered the static weight prediction of the animal. A regression correlation (r^2, R-squared) was performed between the predicted static weights for each data set and their known static weight values at various M values, as well as a Bland-Altman Limits of Agreement tests at various M values. These regressions and limits of agreements for 2 Scale Beef Cattle are shown in Appendix E, 3 Scale Beef Cattle Appendix I, and 3 Scale Dairy Cattle Appendix M.

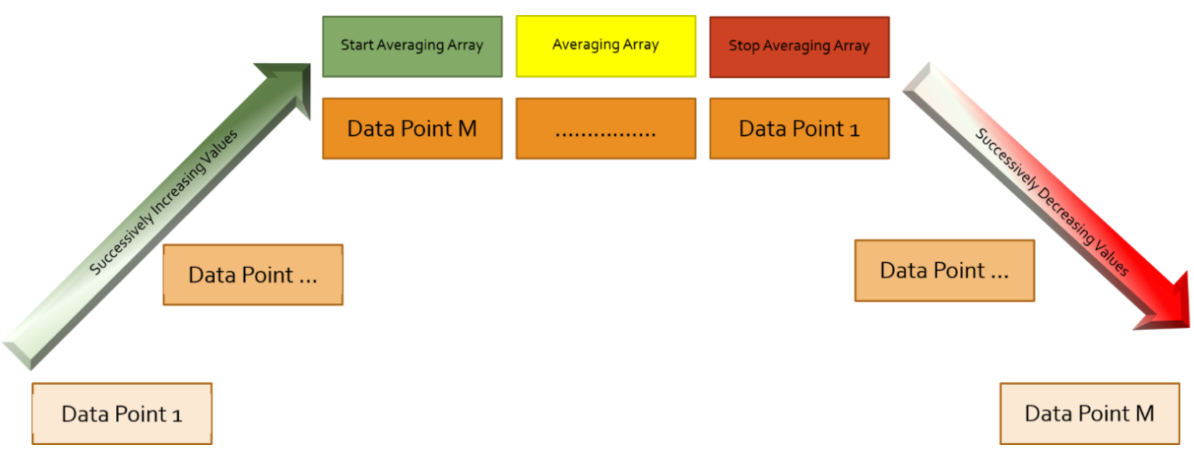


Figure 37 SID Analysis Method Generic Flow Chart.

Average Everything Between Analysis Method

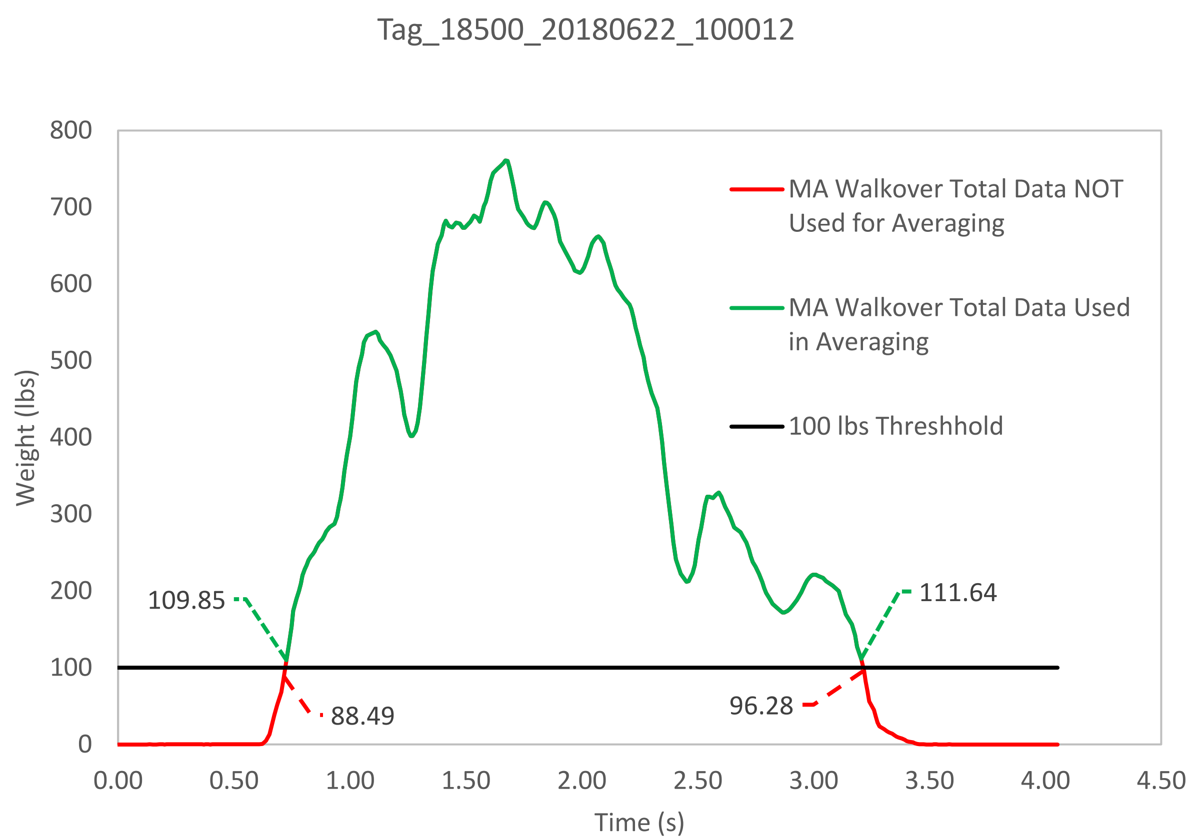


Figure 38 AEB Analysis Method Generic Flow Chart.

Pieper et al was trying to use the weight on the scale as well as the comparison between data points as a method for determining when to begin and end the data array for averaging. A similar concept was performed, but instead of using a comparison of individual data points, the analysis method started a the beginning of the data set and checked every data point until it met a weight threshold (example: weight threshold = 100 lbs). This row was logged as starting point for the averaging array. Then the analysis method started at the end of the data set and checked every data point going backwards until the data was over the weight threshold. When the data from the end met the weight threshold the row was logged as the ending point for the averaging array. All data points between the starting point of the array and ending point of the data array was averaged together. Various weight thresholds were used. Figure 38 illustrates this analysis method for a weight threshold of 100 lbs. 88.494

lbs and 109.848 lbs as well as 111.639 lbs and 96.278 lbs are data point values which are next to each other in the data sets. With a weight threshold (Wt_threshold in regression table, Appendix I, Appendix J, Appendix N) of 100 lbs, the beginning of the data starts at 109.848 lbs and averages all data points up to and including 111.639 lbs.

Fast Fourier Transform (FFT) Analysis Method

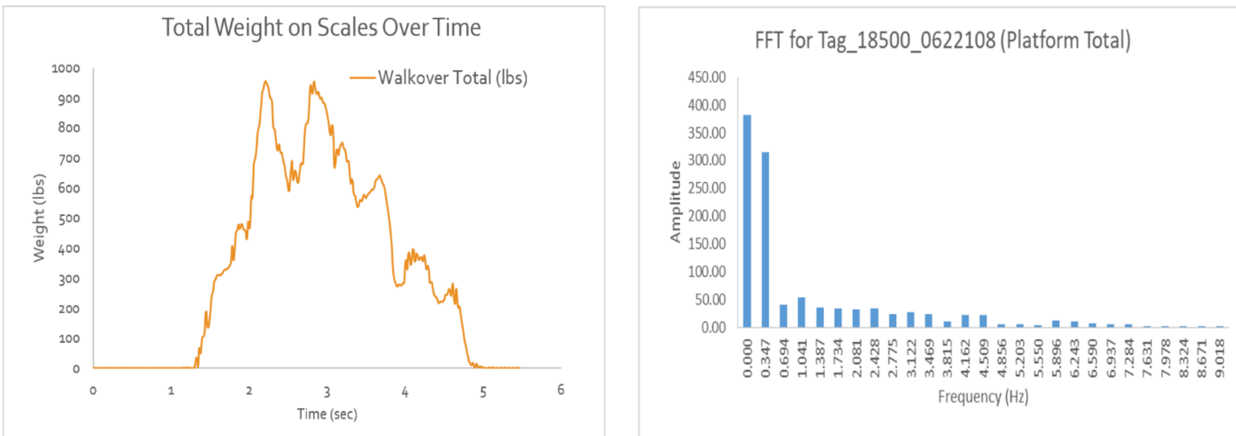


Figure 39 FFT Time Domain (LEFT) vs Frequency Domain (RIGHT)

Fast Fourier Transforms (FFT) converts a signal input from a conventional time domain (left side, figure 39) to a frequency domain (right side, figure 39). This is useful in determining recurring sub-signals from within a larger input signal. When performing FFTs, the total data range must be a power of 2. Using the Excel Add-In “Data Analysis” an FFT was performed on the un-averaged data of each scale individually, as well as combinations of scales. This decision was made based on the idea that FFTs calculate for recurring frequencies in data sets produced from signals, and averaging data may mask some of these lower end frequencies.

The output from using the FFT input yields complex numbers (real number + imaginary number) for each data point in a data range. These output numbers are inserted into a column to the right of the original data. Next, the excel function “IMABS” is applied to each complex number produced by the FFT. The IMABS function calculates the absolute value of each complex number. The absolute values are inserted into a column to the right. Amplitude of each frequency is calculated for graphing. Amplitude is calculated using the formula:

$$A = 2 * I / N \quad (17)$$

A = Amplitude

I = IMABS number

N = number of data points used in the FFT (must be a power of 2)

All amplitudes are calculated using equation 17 with the exception of the first amplitude. The first amplitude does not multiply I / N by 2, the equation is just I / N.. The first amplitude is the zero or DC frequency. DC frequencies are frequencies which do not vary with time, and are considered none recurring signals (Wang 2018).

Lastly, since FFTs are used to convert a signal from a time domain to a frequency domain, the frequency of each amplitude must be calculated. Frequency calculations uses equation 18 (Wang, 2018):

$$F = F(-1) + fs / N \quad (18)$$

F = frequency (Hz)

F(-1) = frequency from previous amplitude

fs = sampling rate (Hz) = 1 / time between data points

N = number odd data points used in the FFT (must be a power of 2)

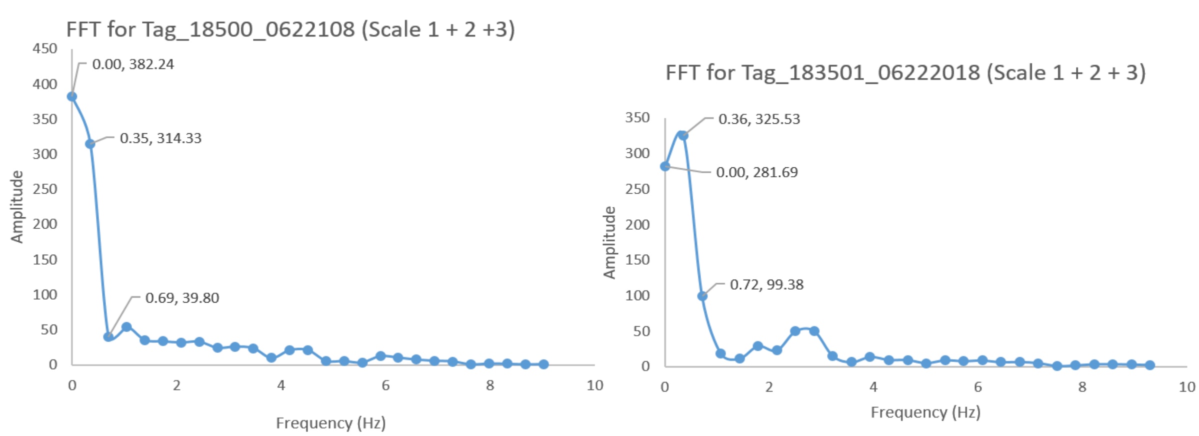


Figure 40 FFT comparisons.

The Microsoft Excel function "CORREL" provides correlations between data. Several correlations of each scale combination were performed. Each of the scales, and scale combinations had the amplitude of the DC value, amplitude of the first frequency past DC value, also referred to as the first harmonic frequency, and maximum amplitude of first two frequencies, compared against the known static weights. Since FFTs calculate for recurring frequencies in data sets, a possibility occurs where the DC value is not the greatest amplitude. This concept is illustrated in Figure 40. The left FFT graph in Figure 40 shows the highest amplitude at the DC frequency. While the right FFT graph show the first harmonic frequency amplitude as the highest amplitude value.

Root Mean Square of the Frequency Analysis Method

Since cattle spend differing amounts of time on the multi-scale walkover platform, the Root Mean Square (RMS) of the Frequency analysis method was chosen. This analysis method normalizes the data regardless of the amount of time an animal spent on the scales.

To approximate the area under a curve, this study used the Root Mean Square of Frequency method. The Root Mean Squared uses the formula:

$$f_{\mathrm{rms}} = \sqrt{\frac{1}{T_2 - T_1}\int_{T_1}^{T_2} [f(t)]^2 \, dt} \qquad T_1 \le t \le T_2 \tag{19}$$

f_{rms} = Root-mean-square value of the frequency

T_2 = Index value for final data point

T_1 = Index value for first data point

Integration = Sums of Square values of data range (lbs^2)

Several weight thresholds were used when computing the root mean square of the frequency. 1.0 lbs, 5.0 lbs, and 10.0 lbs were chosen to see if any change in values occurred. Like the Average Everything Between analysis method, each data point starting at the beginning of the data set was checked until a data point was at or above the weight threshold, at which point the beginning of the data averaging array was marked by logging the index value. Then beginning at the end of the data set and working backwards through the data set, each data point was checked until the data points were equal to or above the weight threshold. At this point the ending point of the data set was marked by logging the index value. The sum of squares for each data point was calculated using the Excel function "SUMSQ([data array])". The sum of squares (equation 19) was added together and divided by the difference between the ending index value and the beginning index value. Lastly, the square root of divided value was taken. Unlike in the Averaging Everything Between Technique, only lower end weight thresholds were taken because the researcher on this study ran out of time and did not have time to perform higher weight thresholds for all scale combinations in all portions of this study.

Bland-Altman Limits of Agreement

Bland Altman Limits of Agreement measures the difference between two sets of data. In the case of this study, Bland-Altman measures the difference between the predicted static weight of each animal and the known static weight. Four variables are recorded, mean difference, standard deviation of the difference, upper limit, and lower limit. Bland-Altman uses a confidence of 0.05. The mean difference was calculated by averaging all of the differences. Differences were calculated by subtracting the predicted static weight minus the known static weight. The mean difference shows whether a positive or negative bias occurs in the predicted static weights. The upper limit of the Bland-Altman Limits of Agreement is the second standard deviation (2σ) of the difference above the mean difference. The lower limit of the Bland-Altman Limits of Agreement is the second standard deviation (2σ) of the difference below the mean difference.

When comparisons between the predicted static weights and the known static weights, every analysis method except FFTs predicted weights in pounds. The same comparisons were made with the outputs from the FFT analysis, but with the amplitude values were considered the predicted static weights.

As seen in figure 41, the differences between the predicted static weight and the actual static weight is the y – coordinate, and the mean (average) of the predicted static weight and the actual static weight is the x – coordinate. The mean line (orange line) is the mean of all the differences (figure 41). The upper line (green line) is two standard deviations (2σ) above the mean, and the lower limit (blue line) is two standard deviations (2σ) below the mean (figure 41). The limits on a Bland-Altman graph, with an alpha of 0.05, show that ninety-five percent of the differences fall in between the upper and lower limits. Figure 41, indicates that when using the Average Everything Between analysis method to analyze the summation of all three scales together in the 3 – Scale Beef Cattle portion of this study, at a weight threshold of ninety pounds, the predicted static weights, on average, are 106.80 lbs less than the actual static values and that 95% of the predicted static weight fall between 19.71 lbs less and 193.89 lbs less that the known static weights.

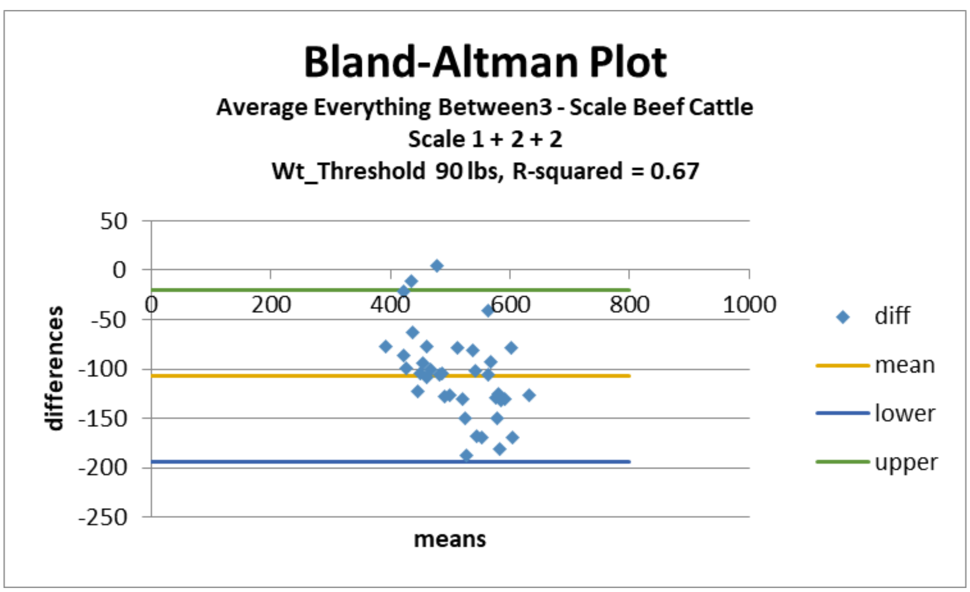


Figure 41 Bland-Altman Example Plot..

In the case of this study, low standard deviations of the difference, would show that the prediction method is precise in predicting the static weight of the animal, while a mean difference close to zero indicates high accuracy of prediction. The standard deviation of the difference could play the most important role in decision making for this study. A low standard deviation indicates a narrow bell curve, assuming the data is normally distributed.

CHAPTER IV

Results and Discussion

Preliminary Data / Center of Mass Calculations

Preliminary data collection yielded a highly accurate set of scales, when calibrated using the HX711 library. Table 2 illustrates this point, as all of the scales were below a 1% diff between actual known weight, and the output weight of the scales. As previously mentioned the accuracy for each scale is 1.42 lbs. Additionaly, the cotton gin weights on the scales were known down to the whole pound.

	Scale 1	Scale 2	Scale 3
Data Readings (lbs)	295.70	497.55	401.08
True Weight (lbs)	295	498	401
% diff	0.24%	0.09%	0.02%

Table 2 Preliminary Data

Preliminary center of mass calculations assumed the x-axis as the bottom 37.75 inch side of the scale and the y-axis as the left 38.25 inch side (figure 32). The preliminary data shows that the accuracy of prediction was generally high with a few outliers, mainly the X coordinate prediction when the weight was by load cell 5 (Table 3). Center of Mass calculations were not performed on the data sets, due to priority of time and resources being given to the prediction of cattle weight.

Cotton gin weight by	X Coordinate Predicted (in)	X Coordinate Actual	X % diff	Y Coordinate Predicted (in)	Y Coordinate Actual	Y % diff
LC1	10.11	10.250	1%	30.65	31.000	1%
LC2	10.17	10.375	2%	6.45	6.250	3%
LC3	31.79	31.375	1%	31.16	31.500	1%
LC4	29.91	29.750	1%	8.57	8.375	2%
LC5	5.76	5.250	10%	31.39	31.500	0%
LC6	11.08	11.375	3%	6.95	6.875	1%
LC7	28.68	28.750	0%	26.13	26.125	0%
LC8	26.10	26.750	2%	7.82	7.575	3%
LC9	9.86	9.875	0%	27.60	27.750	1%
LC10	9.69	9.875	2%	8.64	8.500	2%
LC11	27.47	27.500	0%	28.67	28.875	1%
LC12	32.87	32.875	0%	5.88	5.500	7%

Table 3 Center of Mass (COM) Data. X and Y coordinates are from the bottom left corner of each scale.

Data Sets

A total of 66 data sets were obtained during the morning of testing for the 2 scale walkover study. Only 46 data sets were used during data analysis due to either not pairing with a static data set or improper data readings by the walkover scales. Some reasons for not pairing with a static data, were wrong numbers called out by the operator of the static scale and/or mishearing/typing by the operator of the walkover scales.

47 total data sets were collected during testing of the 3 scales at the OSU Pure Bred Beef Center over two days, but there were only 38 total data sets for a walkover study of 3 scales in which to perform data analysis. Nine of the data sets had to be removed from data analysis due to either not pairing with a static data or improper data readings by the walkover scales. Some reasons for not pairing with a static data was wrong numbers called out by the operator of the static scale and/or mishearing/typing by the operator of the walkover scales.

Reasons for bad data are illustrated in figure 42, and shown by yellow highlights in Appendix G for the 2-Scale Beef Cattle, and Appendix H for the 3-Scale Beef Cattle. Some data sets, for unknown reasons, were negative in value. Bad data set are likely caused by the operator of the walkover scales not beginning the data collection program fast enough. When the program begins, the “scale.read” function in the Arduino code, along with the HX711.h file (library) “zeros” the scale. If the animal is on the scale when the zeroing occurs, then when the animal leaves the scale, the scale will read significantly less than zero. While it is possible to shift the scale upwards, and use the data, there is typically not enough walkover data collected to describe a full walkover event.

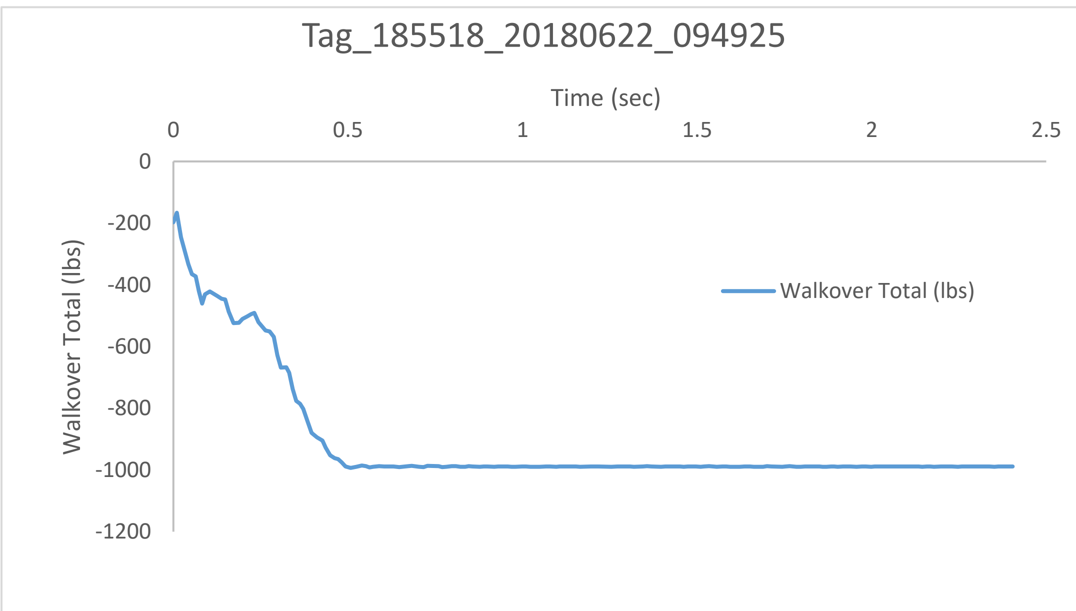


Figure 42 Example of Bad Walkover Scale Data

Moving average data sets were computed from the original data. Each of the scales individually (Scale 1, Scale 2, Scale 3), as well as several combinations of the scales (Walkover Total or All scales summed, Scale 1 + 2 summed, Scale 2 + 3 summed). All data analysis, with the exception of FFT analysis, occurred on these moving average data sets.

Data Analysis

Not all data sets met the requirements for each threshold in each of the analysis methods. Therefore, .when analyzing and considering data for the 2 - Scale and 3 - Scale Beef Cattle portions of this study, a minimum of thirty data sets used was required to be able to consider any statistical analysis relevant. However, due to the lower number of data sets with 3 – Scale Dairy Cattle, a minimum of twenty data sets were required for consideration. In Appendix E through Appendix P, the boxes highlighted in red to not meet the minimum number of data sets used requirement. If the cells are highlighted red, they are not a part of the figures in this subsection because the number of data sets was below the statistical minimum of 30 for the Beef Cattle, and below the studies minimum of 20 for the Dairy Cattle)

Two different numbers of scales were tested (2-Scale and 3-Scale), to test how many scales was necessary to predict the static weight of an animal from their dynamic walkover weight. Effectively, can an analysis method predict the static weight of an animal from their dynamic walkover weight with the short platform of two scales, or does the analysis method need the extra length of platform provided by three scales.

The dynamics of how the animals enter and exit the scale are different for each portion of this study. In the 2-Scale Beef Cattle portion of this study, Scale 1 requires the animal to step up onto the scale and step on a level surface off of scale 1. Scale 2, the animal enters onto from a level plane, then steps off down onto the ground.

The 3 scale portions of the study also has different entrance and exit dynamics for each scale. Since scale 1 and scale 3 are beginning and ending scales respectively, their dynamics should be similar to that of the 2 scale portion of the study, but since there is scale 2 in the center, the dynamics change slightly. Again, Scale 1 requires the animal to step up and onto the scale platform from the ground, and the animal exits the scale in the same plane as the scale. Scale 2, the animal enters from the same plane and exits in the same plane. Scale 3, the animal enters in the same plane as the scale, but when exiting the animal steps down off the scale onto the ground. Therefore, the dynamics for entering and exiting Scale 1 and Scale 3 in the 3-Scale portions of this study are similar to the of Scale 1 and Scale 2, respectively, for the 2-Scale portion of this study.

When data analysis was performed. All combination of scales were performed. In the 2-Scale beef cattle, three data sets had various analysis performed on their moving averages; Scale 1, Scale 2, and Scale 1+2. Scale 1 was the summation of load cell one (LC1) through load cell four (LC4) for each data array (data row in Table 1).. Scale 2 was the summation of load cell one (LC5) through load cell four (LC8) for each data array (each row in excel, 1). Scale 1+2 was the summation of data values from Scale 1 and Scale 2.

In the 3-Scale portions of this study seven data sets had various analysis performed on their moving averages; Scale 1, Scale 2, Scale 3, Scale 1+2, Scale 2+3, Scale 1+3, and Scale 1+2+3. Scale 1 was the summation of load cell one (LC1) thorugh load cell four (LC4) for each data array (data row in Table 1). Scale 2 was the summation of load cell five (LC5) through load cell eight (LC8) for each data array (data row in Table 1). Scale 3 was the summation of load cell nine (LC9) through load cell twelve (LC12) for each data array. Scale 1+2 was the summation of data values from Scale 1 and Scale 2. Scale 2+3 was the summation of data values from Scale 2 and Scale 3. Scale 1+3 was the summation of data values from Scale 1 and Scale 3. Scale 1+2+3 was the summation of data values from Scale 1, Scale 2, and Scale 3.

The different combinations of scales for both ther 2-Scale and 3-Scale portions of the study was performed to test wether an individual scale, within each setup, was long enough to predict the static weight of an animal, or if multiple scales, in each setup, was necessary. The combination of one or two scales effectley assumes a “zero” reading from the other scale(s). This was preliminary testing for PASS, as there is a potential for one or more of the scales to "go down" or be rendered incapable of collecting data in the field.

2-Scale Beef Cattle

Successive Increase/Decrease in Data Values Analysis Method

Statistical Analysis for Successive Increase/Decrease (SID) in Data Values Analysis Method for the 2 – Scale Beef Cattle portion of this study can be found in Appendix E.

In the 2 scale beef cattle portion of this study using the SID analysis method, figure 43 shows the trend of the R-squared values. Statistical analysis values can be found in Appendix E. Scale 1 generally had low R-squared values. R-squared values started at 0.01 at an m_threhold of 5 and rose to maximum R-squared of 0.16 at an m_threhold of 19, then steadily declined back to an R-squared of 0.01 at the final m_threhold of 30.

Scale 2 started at an R-squared of 0.00 at an m_threhold of 5, indicating no linear correlation, but generally increase as the m_threshold increased and ended at its' highest R-squared value of 0.22 (m_threshold of 30).

The summation of Scale 1 and Scale 2 (Scale 1 + 2), as with the individual scales, began at a low R-squared value of 0.00 (m_threshold of 0.00) but peaked at an R-squared of 0.39 (m_threshold of 23). Then the R-squared values for Scale 1 + 2 lowered to finish at an R-squared of 0.16 (m_threshold of 30).

These R-squared values though increasing are not what this study would consider great enough to say that there is any correlation between the predicted static values and the known static values using the SID Analysis Method with 2 scales.

Though there does not appear to be a correlation between the predicted static weight and the known static weight of cattle using the SID analysis method for the 2 – Scale Beef Cattle portion of this study, other means of analysis occur.

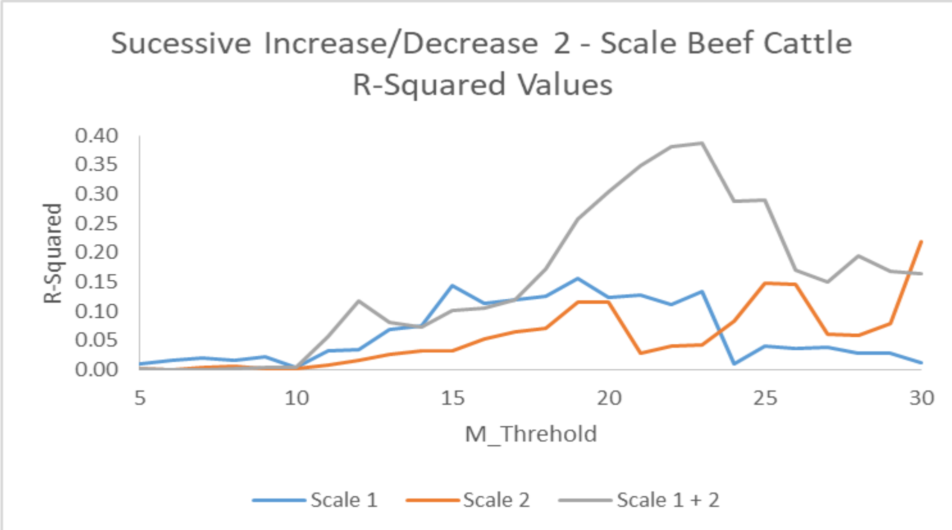


Figure 43 SID Analysis Method R-squared values

Using the Bland-Altman Analysis Limits of Agreement method, the mean difference (mean diff as seen in figure 44) for each threshold is this analysis method reveals that each of the predicted static weights for Scale 1, Scale 2, and Scale 1 + 2 predict lower than the true (known) static weight of each animal. Figure 44 shows these low predictions. Figure 44 shows that as the m threshold increases, the mean difference between predicted static weights and known static weight becomes smaller, with Scale 1 + 2 being the best, and narrowing the mean difference to at best -101.76 lbs at an m threshold of 25 (Appendix E).

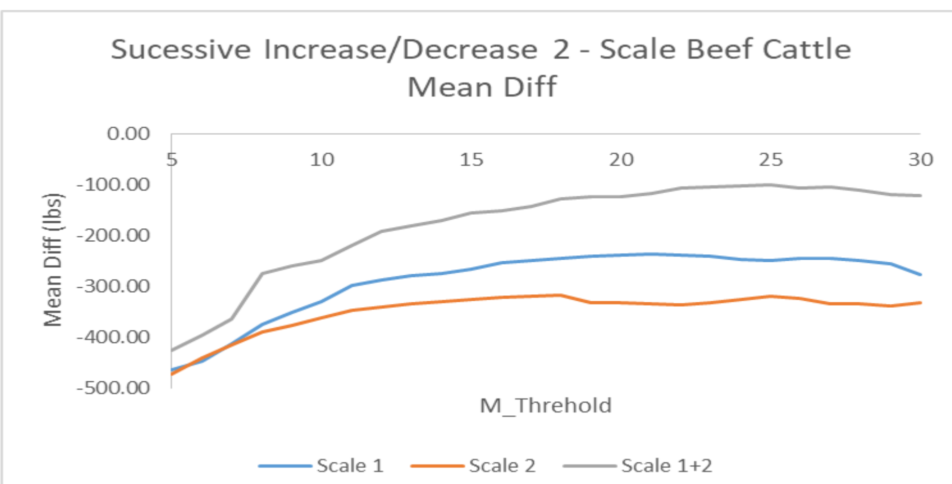


Figure 44 SID Analysis Method Mean Difference

Though these difference between the predicted weights and the known static weights narrow, one must also consider the standard deviation of the difference. Figure 45, shows that the standard deviation of the difference for Scale 1, Scale 2, Scale 1 +2, decrease as the m_threhold increases, and that Scale 2 and Scale 1 + 2's lowest standard deviation of the difference are 70.70 lbs (M_Threshold 25), and 65.14 lbs (M_Threshold 23) respectively. While Scale 1's lowest standard deviation is 86.31 lbs (M_Threhold 15). The second lowest standard deviation of for Scale 1 is 87.86 lbs (M_Threshold of 23) which is not much different from Scale 1's lowest standard deviation.

Since the mean difference for each of Scale 1, Scale 2, and Scale 1 + 2, at their highest points, and tend to be similar between M threshold of 20 to 30, and the lowest standard deviation for each of the scales is around an M Threshold of 23, its seems the best predictor of static weights for the SID for the 2 – Scale Beef Cattle portion of this study would be an M Threshold of 23.

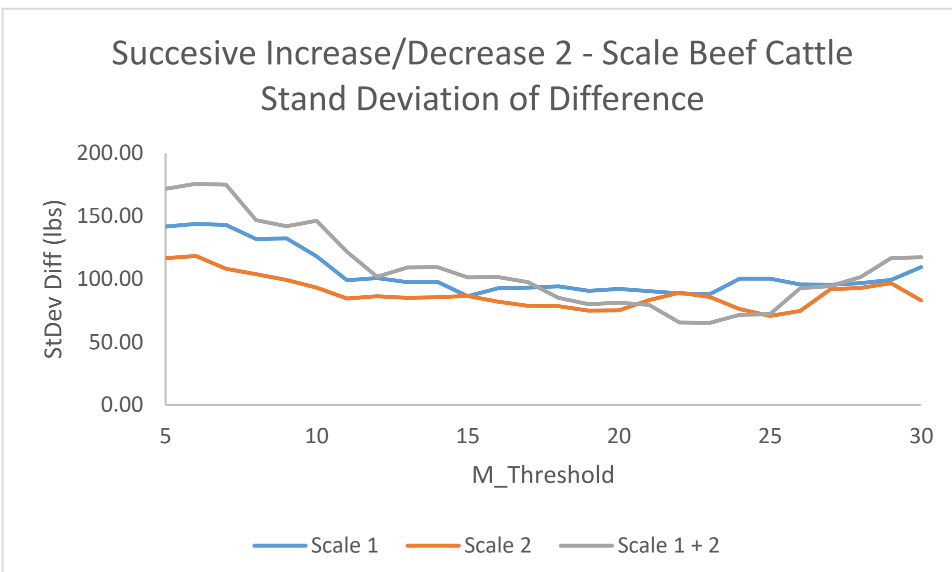


Figure 45 2-Scale Beef Cattle SID StDev Difference

Average Everything Between Analysis Method

Statistical Analysis for Average Everything Between (AEB) analysis method for the 2 – Scale Beef Cattle portion of this study can be found in Appendix F.

Figure 46, illustrates the R-squared values for the 2-Scale Beef Cattle portion of this study when using the AEB analysis method. The general trend for the R-squared values for all scale combinations is that as the weight threshold increases the R-squared values decrease. Scale 1+2 always had a better R-squared values than Scale 1 and Scale 2, but with one exception with Scale 1+2, R-squared of 0.50 at a weight threshold of 350 lbs, no R-squared values were above 0.50, indicating there is not a correlation between predicted walkover weights and static walkover weights of cattle when using the AEB analysis method in the 2-Scale Beef Cattle portion of this study.

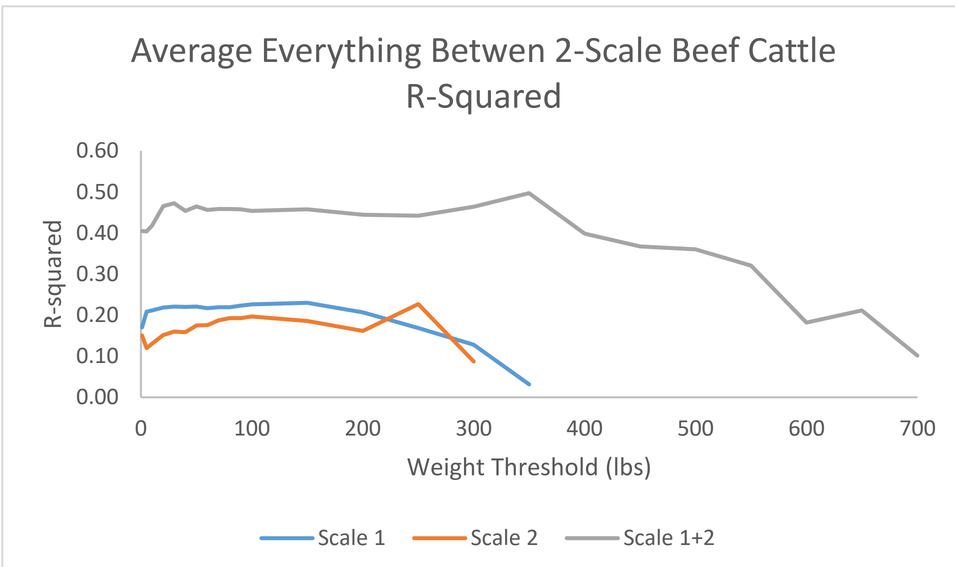


Figure 46 2-Scale Beef AEB R-squared.

The AEB analysis method for the 2-Scale Beef Cattle portion of this study say closer average predictions than the SID analysis method for the same portion. Again, Scale 1+2 was closer at predicting the static weight of the animal than either Scale 1 or Scale 2, with Scale 1+2 eventually over predicting the static weight of the animals between 400 lbs and 450 lbs (figure 47). As the weight threshold of the AEB analysis method increased, all scales, on average, were predicting closer to known static weights. As previously mentioned, if the number of data sets which met the weight threshold was less than 30, their mean differences were not graphed in figure 47. In the case of the 2-Scale Beef Cattle portion of this study, it is not surprising that the individual scales did not predict static weights above 350 lbs, as the scales only measure half the body weight of the animal at a time, and the average known body weight of all the animals was 583 lbs.

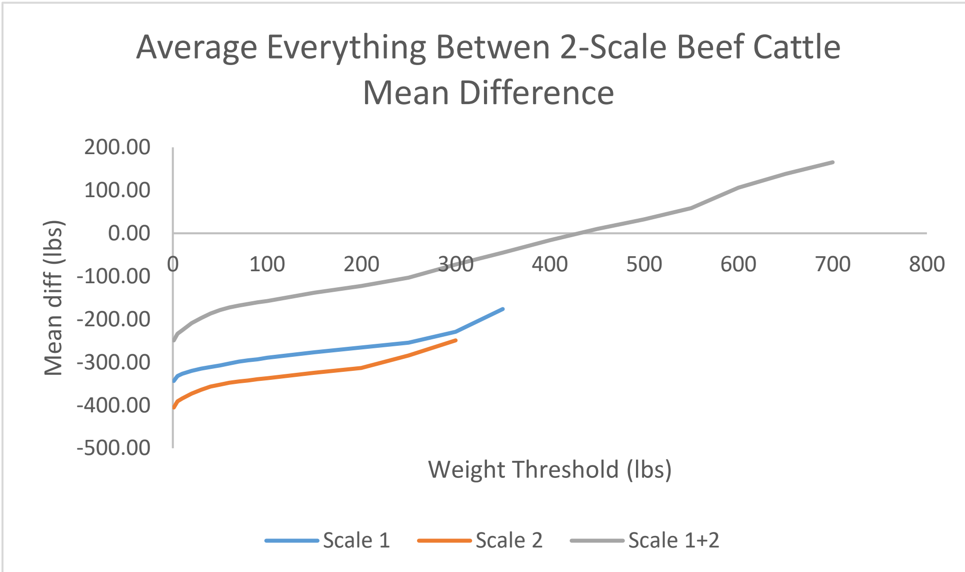


Figure 47 2-Scale Beef AEB Mean Difference.

As illustrated in figure 48, the standard deviations of the difference for the analysis method AEB analysis method in the 2-Scale Beef Cattle portion of this study, tended to increase as the weight thresholds increased. This increase in standard deviations of the difference indicates that the range of predictions becomes farther away from the known static weights as the weight threshold increases, though not a lot. Most of the standard deviations illustrated in figure 48 were between 50 lbs and 70 lbs, with Scale 1+2 having the lowest standard deviation of the difference at 49.62 lbs at a weight threshold of 30 lbs.

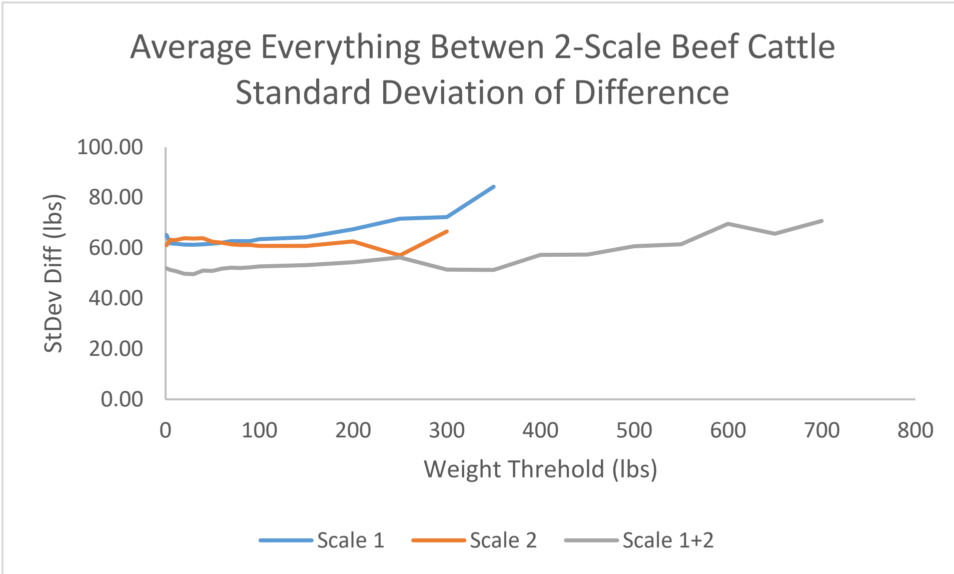


Figure 48 2-Scale Beef AEB StDev Difference

Fast Fourier Transform Analysis Method

Statistical Analysis for Fast Fourier Transforms (FFT) analysis method for the 2 – Scale Beef Cattle portion of this study can be found in Appendix G.

In the 2 Scale Beef Cattle study, when FFTs were performed on all combinations of scales, generally Scale 1+2 had the highest R-squared values regardless of the frequency (figure 49) , with the highest R-squared value being 0.41 at the First Harmonic Frequency. However, none of the R-squared values were over 0.50 indicating no correlation exist between the predicted static weights and the known static weights of the animal for the 2-Scale Beef Cattle portion of the study using the FFT analysis method.

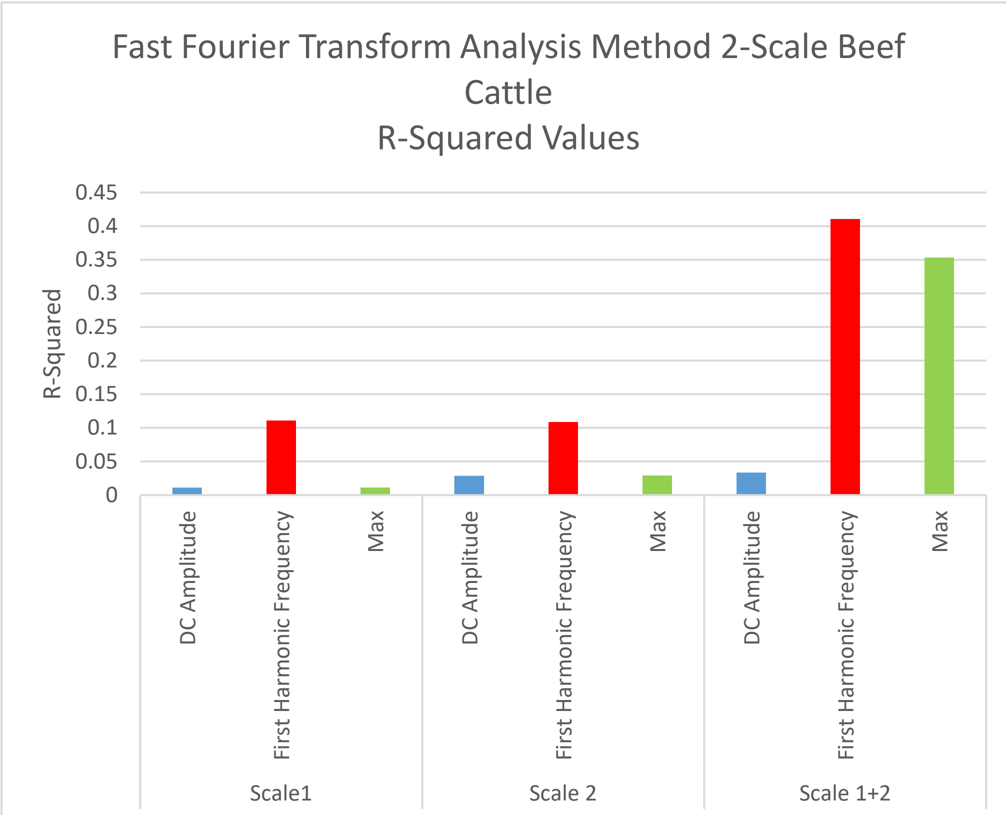


Figure 49 2-Scale Beef FFT R-Squared.

The mean differences for predicted weight values (amplitude values for FFT analysis method) were always lower than the known static weights for the animals. Figure 50, illustrates that Scale 1+2 was the closer, on average, in predicting the static weight on the animal, but was still significantly lower than the known static weight.

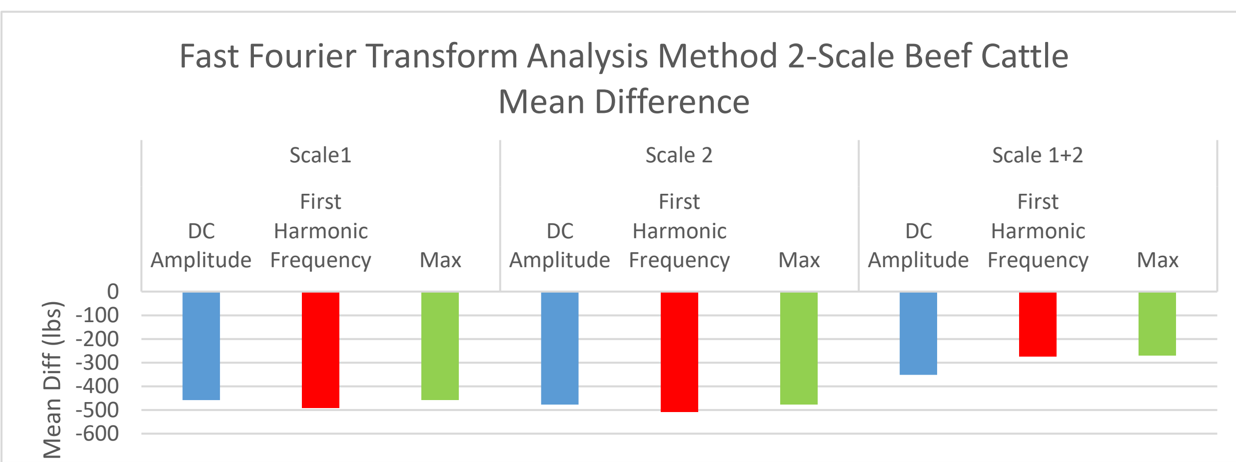


Figure 50 2-Scale Beef FFT Mean Difference

The standard deviation of FFTs for the 2-Scale portion of this study, as seen in figure 51, ranged between 50 lbs and 80 lbs. The lowest standard deviation was 54.24 lbs when comparting the first harmonic frequency amplitudes of Scale 1+2 against the known static weights.

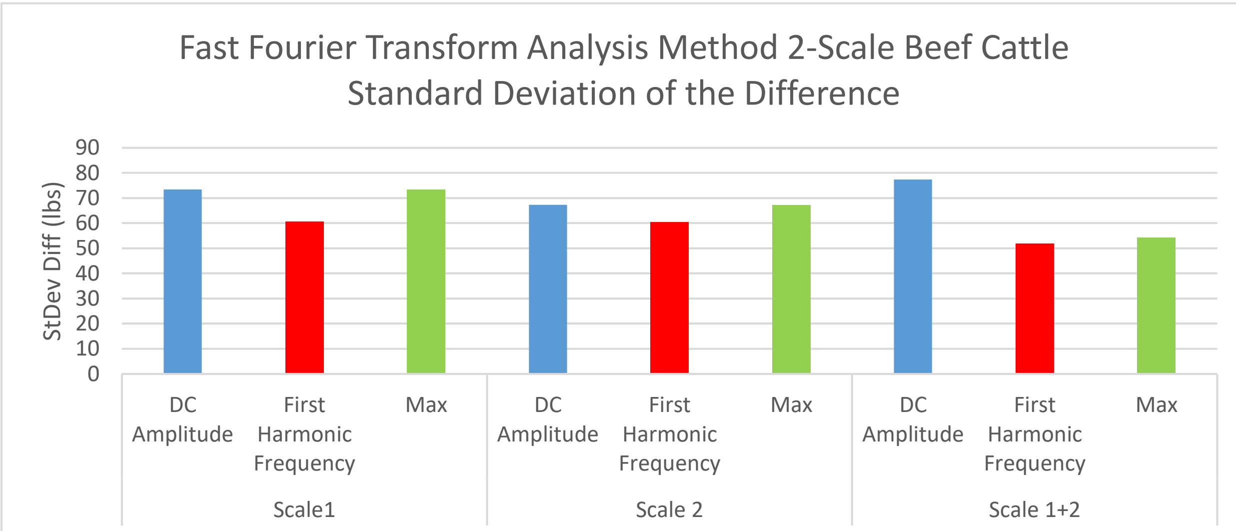


Figure 51 2-Scale Beef FFT StDev Difference.

Root Mean Square of Frequency Analysis Method

Statistical Analysis for Root Mean Square (RMS) analysis method for the 2 – Scale Beef Cattle portion of this study can be found in Appendix H.

The R-squared values for the 2-Scale Beef Cattle portion of this study when using the RMS analysis method, are all bellow 0.50 (figure 52), indicating no correlation between the predicted static weights of the cattle and the known static weights. Scale 1+2's R-squared value was significantly higher for all weight thresholds than the R-squared values of Scale 1 and Scale 2.

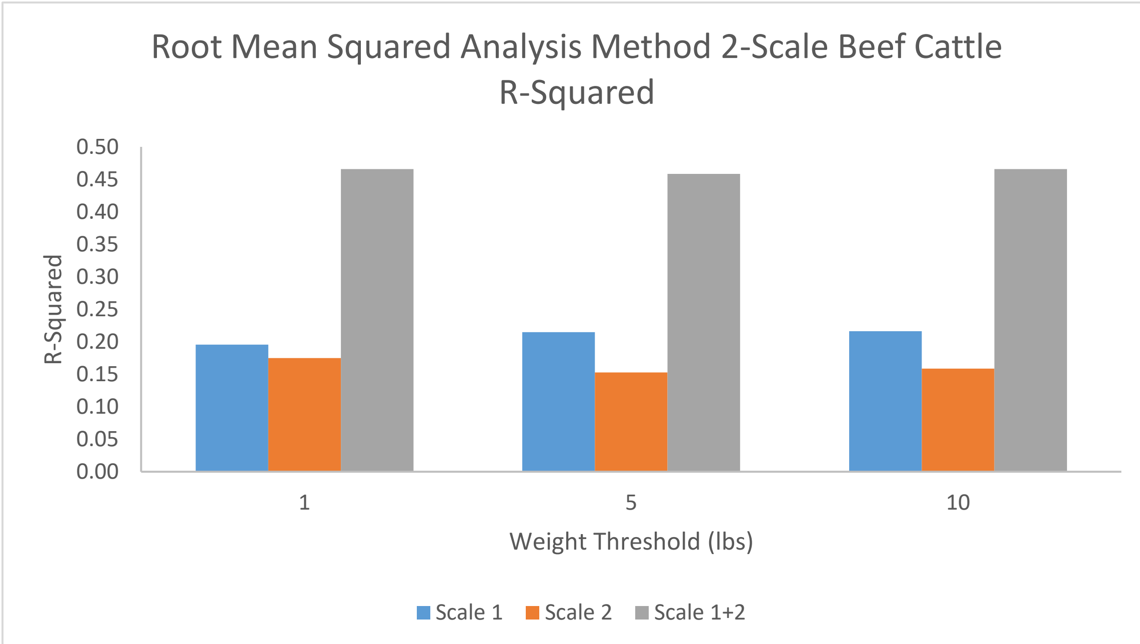


Figure 52 2-Scale Beef RMS R-Squared.

The mean differences for the 2-Scale Beef Cattle portion of this study when using the RMS analysis method, are below zero, indicating that on average, the predicted static weights are lower than the known static weights of cattle. Figure 53, indicates that at a minimum, the mean differences between the predicted static weights and the known static weights is -161.41 lbs (Scale 1+2, weight threshold 10 lbs). As with the other analysis methods, Scale 1+2 is closer at predicting the static weight of cattle than the individual scales of Scale 1 and Scale 2, regardless of the weight threshold.

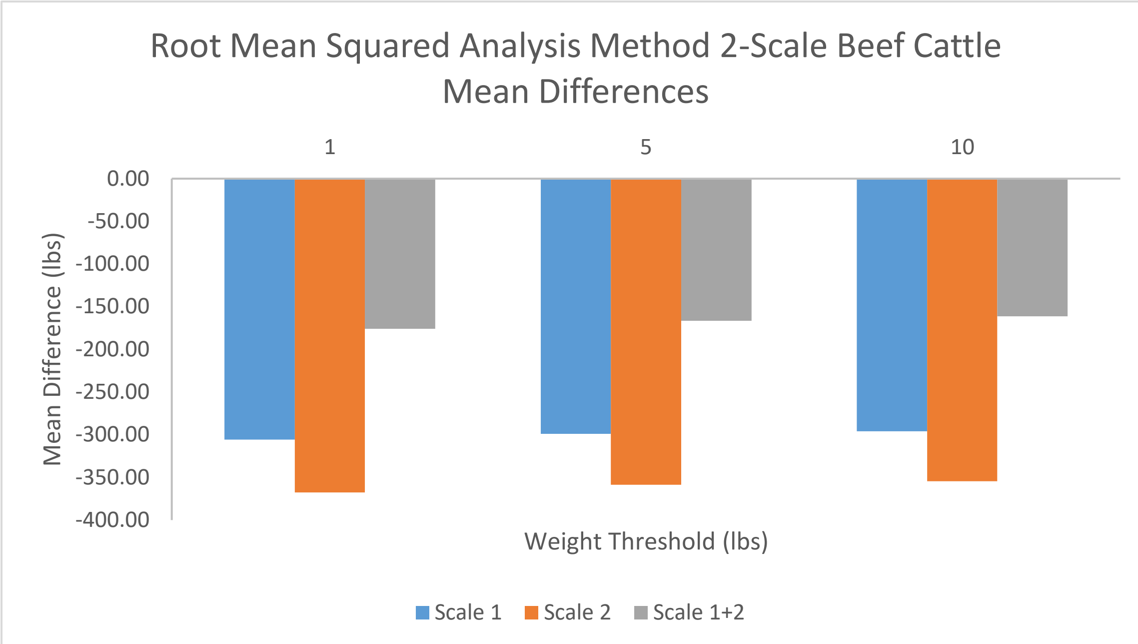


Figure 53 2-Scale Beef RMS Mean Difference.

When using the RMS analysis method in the 2-Scale Beef Cattle portion of the study, the standard deviations of the differences decreases as the number of scales increases (figure 54). Scale 1+2 had lower standard deviations of the differences for all weight thresholds, than the individual scales. The range of standard deviations for all weight thresholds and scale combinations are a low of 52.95 lbs (Scale 1+2, weight threshold 10 lbs) and a high of 67.59 lbs (Scale 1, weight threshold 1.0 lbs) (Appendix H).

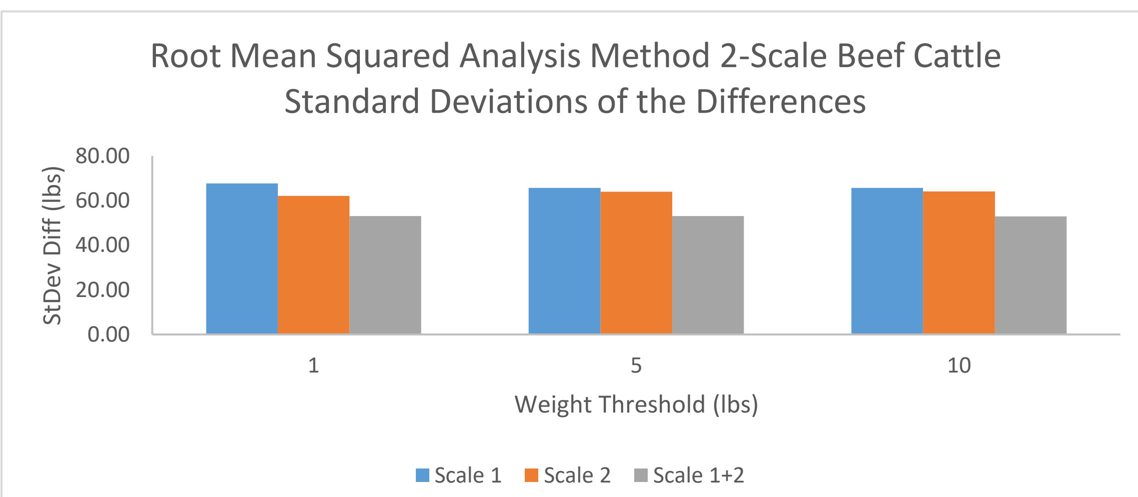


Figure 54 2-Scale Beef RMS StDev Difference.

Comparisons of Scale Combinations

In the 2-Scale Beef Cattle portion of this study, the highest R-squared value calculated was 0.50 using combination Scale 1+2, and using the Averaged Everything Between (AEB) analysis method at a weight threshold of 350 lbs. In general, Scale 1+2 had the highest R-squared values on all scale combinations in the 2-Scale Beef Cattle portion of the study, followed by Scale 1, and lastly Scale 2. With the exception of the highest R-squared value mentioned, no R-squared value was at or above 0.50. Figure 55, illustrates the general comparison of R-squared values for all scale combinations for all analysis methods.

The AEB analysis method was the only analysis method to, on average, over predict the static weight of the animals at certain weight thresholds, and was the closest, on average, to predicting the known static weight of the animal in the 2-Scale Beef Cattle portion of this study. The closest to zero mean difference in the 2-Scale Beef Cattle portion of this study was 9.75 lbs (Scale 1+2) which uses the AEB analysis method, at a weight threshold of 450 lbs. Generally, as illustrated in Figure XX55, Scale 1+2 was closest for each analysis method at each threshold in those analysis methods, to predicting the known static weight of the cattle, followed by Scale 1, and lastly by Scale 2.

Illustrated in figure 55, Scale 1+2 generally had the lowest standard deviation of the difference for all thresholds in each analysis method, with the exception of some m thresholds in the Successive Increase/Decrease in Data Values analysis method. The highest standard deviations of the differences was generally Scale 1. The lowest standard deviation of the difference calculated in the 2-Scale Beef Cattle portion of this study was 49.62 lbs, Scale 1+2, AEB analysis method, weight threshold of 30 lbs.

R-squared

Scale 2 < Scale 1 < Scale 1+2

Mean Difference

Scale 2 < Scale 1 < Scale 1+2

Standard Deviation of the Difference

Scale 1 < Scale 2 < Scale 1+2

Figure 55 2-Scale Beef Scale Accuracy Rankings.

3-Scale Beef Cattle

Successive Increase/Decrease in Data Values Analysis Method

Statistical Analysis for Successive Increase/Decrease in Data Values (SID) analysis method for the 3 – Scale Beef Cattle portion of this study can be found in Appendix I.

R-squared values for the 3-Scale Beef Cattle portion of this study using the SID analysis method were generally better than the 2-Scaled Beef Cattle portion which used the same analysis method. As with the 2-Scale Beef Cattle portion, the R-squared values for all combinations of scales (Scale 1, Scale2, Scale 3, Scale 1+2, Scale 2+3, Scale 1+3, and Scale 1+2+3) were relatively low at the bringing M Threshold of 5, but generally gained as the M Threshold gained (figure 56). The scales with R-squared values above 0.50, which indicates there is a linear correlation between the predicted static weight and the known static weight of the animals, were scale combinations; Scale 3, Scale 1+2, Scale 2+3, and Scale 1+2+3.Both Scale 1+2 and Scale 3 had the highest R-squared of 0.68, at M Thresholds of 24 and 26 respectively.

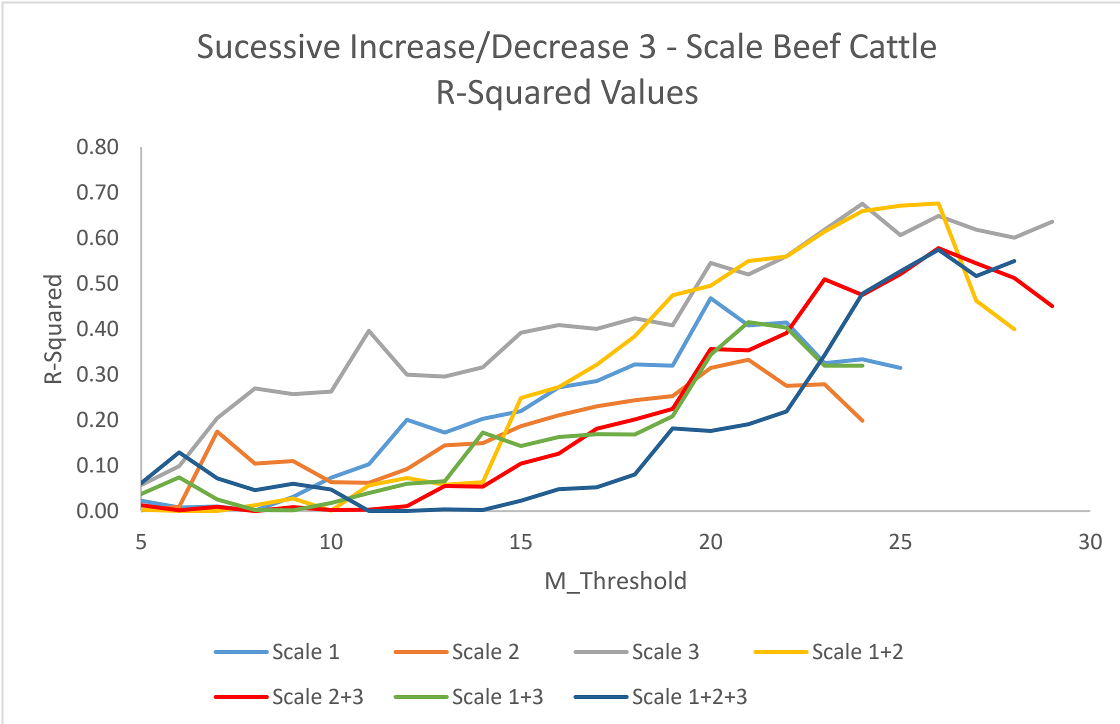


Figure 56 3-Scale Beef Cattle SID R-Squared.

Again, looking at the mean difference between predicted weight values and known static values using the SID analysis method in the 3-Scale Beef Cattle portion of this study, a general increase occurs as the M Threshold increases (figure 57). Generally, most combinations of scales mean difference was closest to zero at M Thresholds between 15 and 20, with the closest being Scale 1+2+3 with a mean difference of -19.20 lbs at an M Threshold of 20. This indicates a mean prediction bias of -19.20 lbs, or on average the combination of Scale 1+2+3 predicts the static weight of the animal 19.20 lbs lower than the actual static weight of the animal.

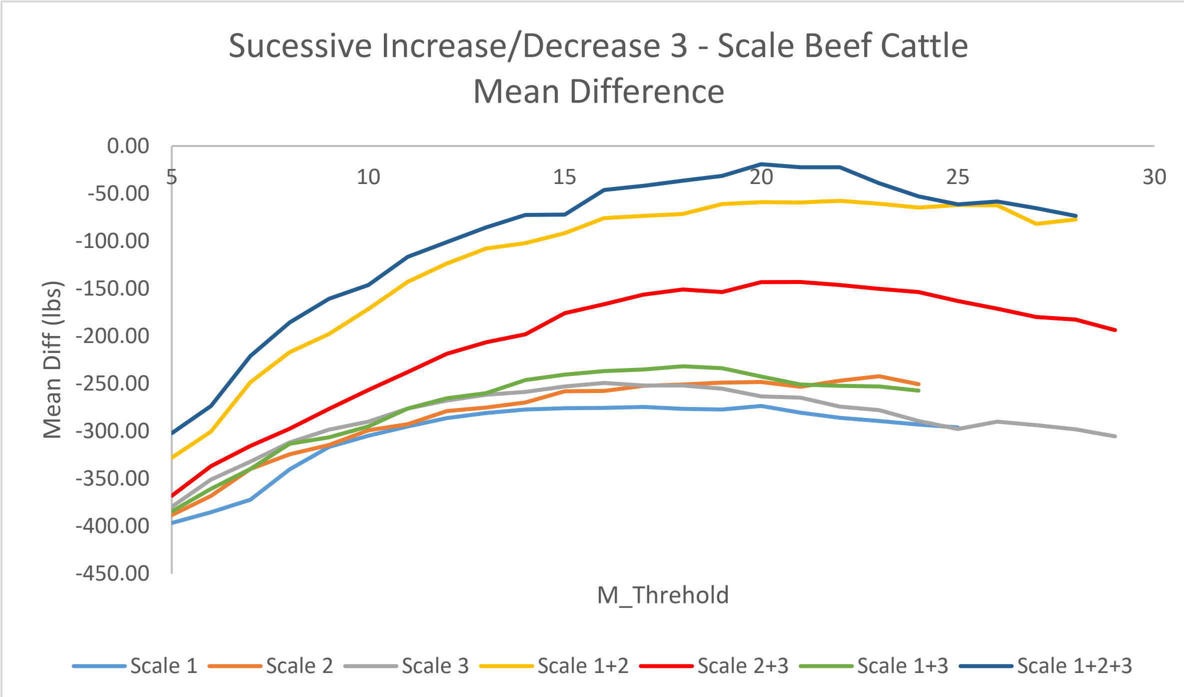


Figure 57 3-Scale Beef Cattle SID Mean Difference.

Similarly to the 2-Scale Beef Cattle portion of this study which used the same analysis method, the standard deviations for each combinations of scales overall decreased as the M Threshold increased (figure 58). The lowest standard deviation of the difference of 47.09 lbs occurred with Scale 1+2 combination at an M Threshold of 25. This suggests that if 62.04 lbs (mean difference at M Threhold of 25) were added to each predicted static weight for the SID analysis method at an M Threshold of 25, using the combination Scale 1+2 in the 3-Scale Beef Cattle portion of this study that the 95% of the weights of the animals could be predicted to with 100 lbs of the true (known) static weight.

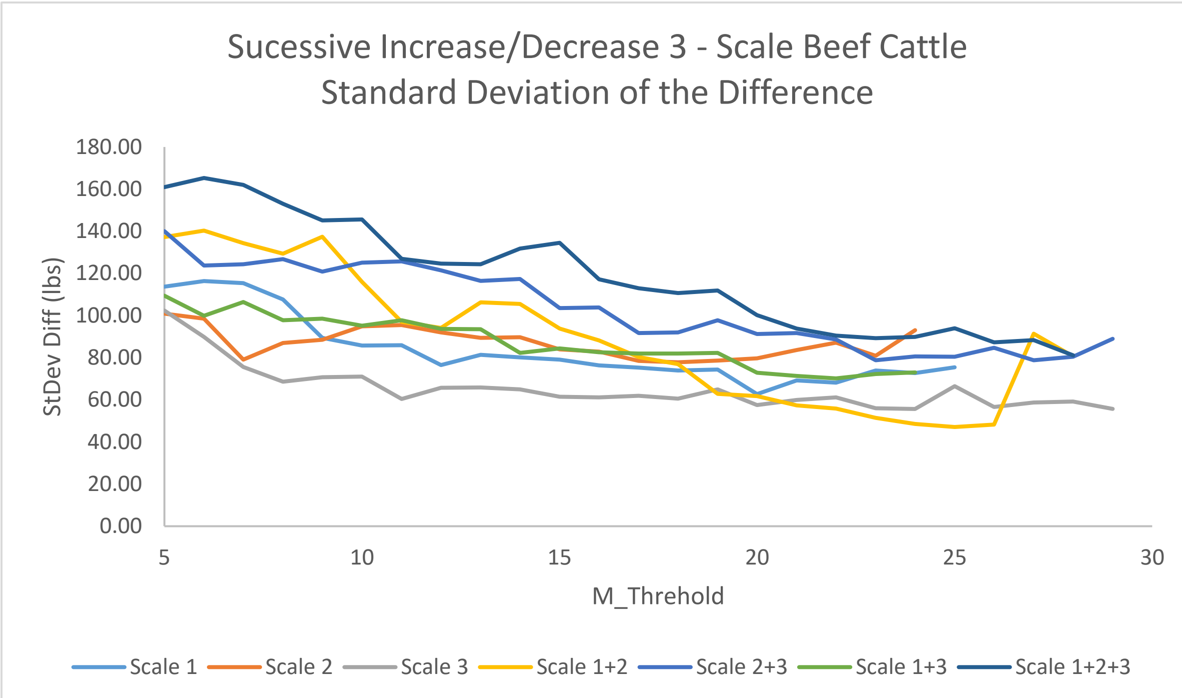


Figure 58 3-Scale Beef Cattle SID StDev Difference.

Average Everything Between Analysis Method

Statistical Analysis for Average Everything Between (AEB) analysis method for the 3 – Scale Beef Cattle portion of this study can be found in Appendix J.

Figure 59, indicates that as the weight threshold for the AEB analysis method increase the R-squared value for the predicted weights vs the known static weight for all the scale comparisons in the 3-Scale Beef Cattle portion of this study decreases. The trending decrease in R-squared values suggests that when using the AEB analysis method, it is better to stay with the lower weight thresholds than to move to higher weight thresholds.

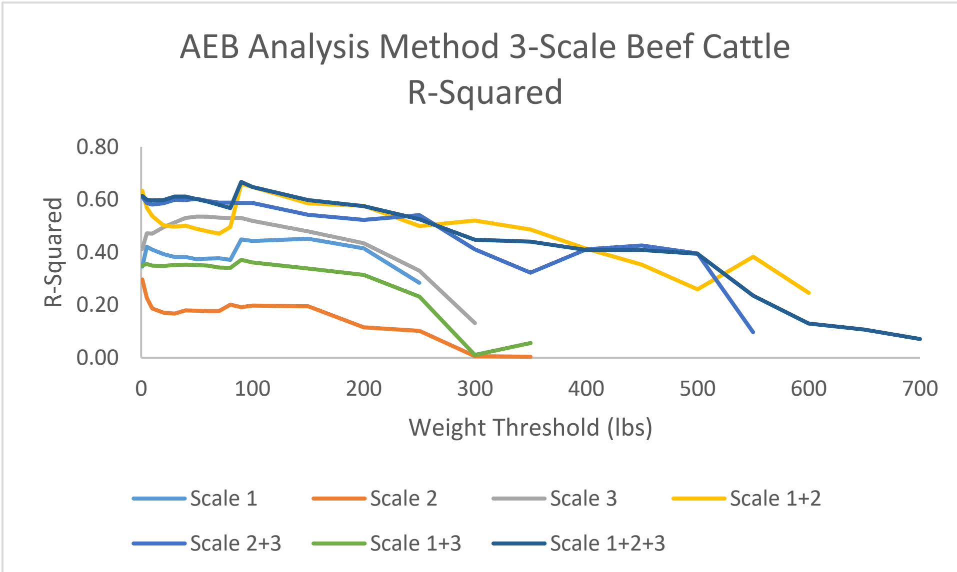


Figure 59 3-Scale Beef Cattle AEB R-Squared.

The mean difference for all scale comparisons generally increases as the weight threshold increases in the AEB analysis method (figure 60). Additionally, figure 60 suggests that the more scales used when predicting static weight values is closer to the known static weight than less scales used. In essence, Scale 1+2+3 is closer to predicting the static weight value than Scale 1+2 or Scale 2+3, and that Scale 1+2 and Scale 2+3 are closer to predicting the static weight values than Scale 1, Scale 2, or Scale 3. This data also suggests that Scale 2 is an integral part in predicting the static weight of an animal.

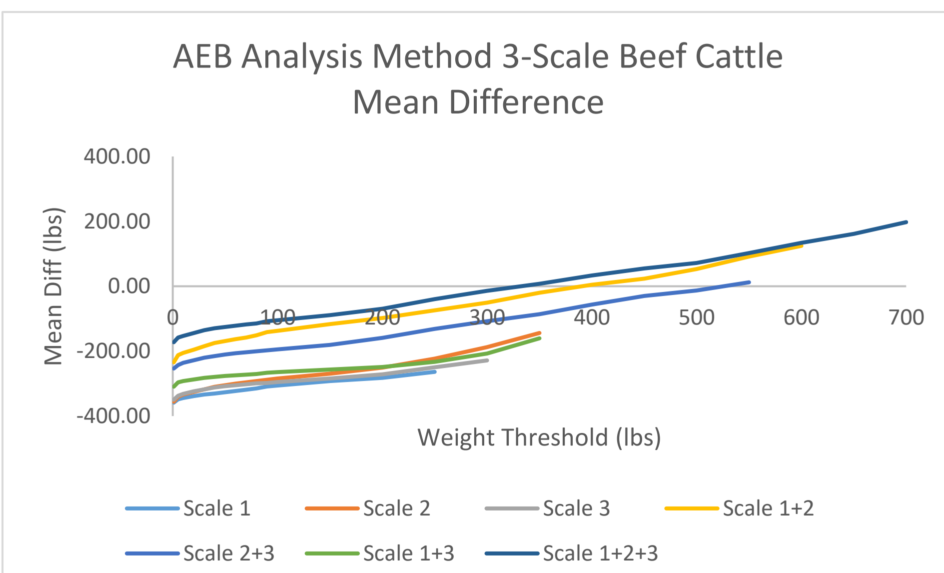


Figure 60 3-Scale Beef Cattle AEB Mean Difference.

The AEB analysis methods standard deviations of the difference for the 3-Scale Beef Cattle portion of this study generally increase as the weight threshold increases, suggesting that to predict the static weight of an animal more precisely, the lower weight thresholds should be used (figure 61). Additionally, the standard deviations of the difference are generally lower when compared to other data analysis methods. The lowest standard deviation of the difference calculated, when using the AEB analysis method for the 3-Scale Beef Cattle portion of the study, was 44.48 lbs (weight threshold of 90 lbs) when all the scales were summed together (Scale 1+2+3). Yet, the lowest standard deviation of the difference for Scale 1+2 was 45.67 lbs (weight threshold of 90 lbs) and for Scale 2+3 was 47.94 lbs (weight threshold of 1.0 lbs).

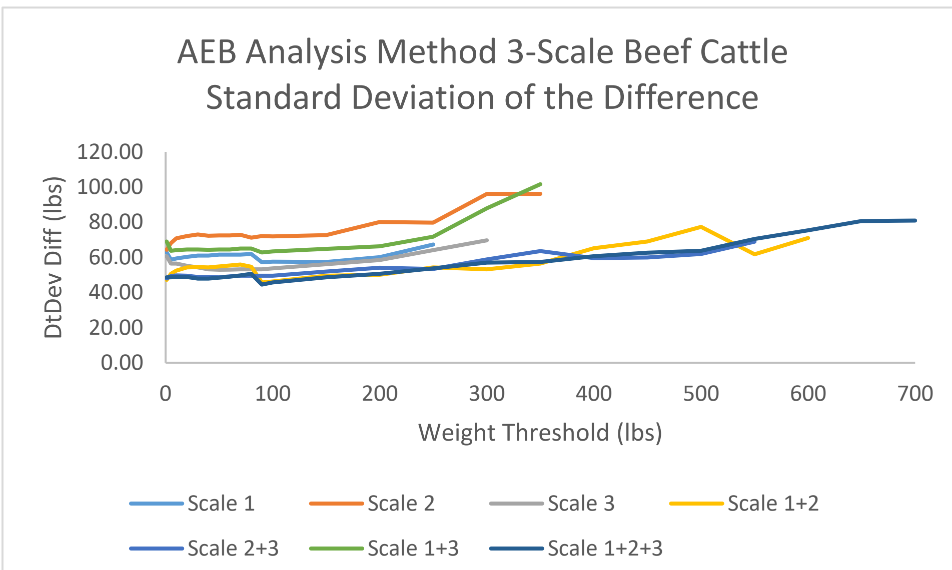


Figure 61 3-Scale Beef Cattle AEB StDev Difference.

Fast Fourier Transform Analysis Method

Statistical Analysis for Fast Fourier Transforms (FFT) analysis method for the 3 – Scale Beef Cattle portion of this study can be found in Appendix K.

The R-squared values for single scales are higher when comparing the amplitude of the first harmonic frequency (FHF) to the known static weights than either the DC amplitude or the max amplitude (figure 62). As the number of scales increases the maximum amplitude becomes the higher R-squared value, with the overall highest R-squared value being 0.53 (Scale 1+2+3, Max of DC or FHF).

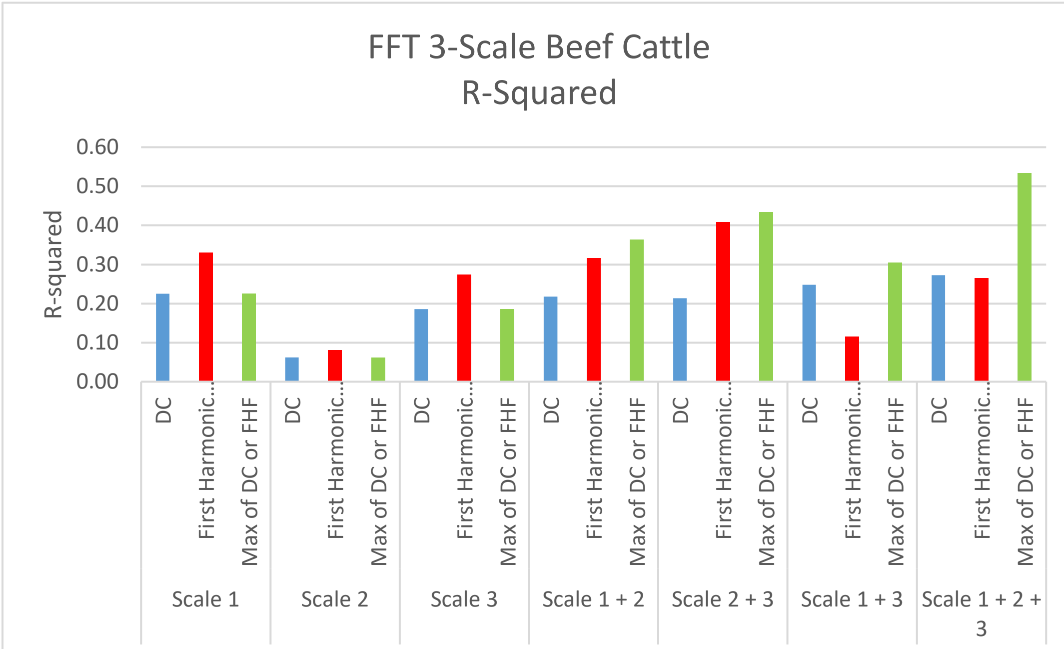


Figure 62 3-Scale Beef Cattle FFT R-Squared.

The mean differences in scale combinations for the DC value, FHF value, and the maximum amplitude value all under estimated the known static weight of the animal. Figure 63, shows that as the number of scales used in the FFT analysis method increases, the average difference between the amplitude values and the known static weight decreases. Also, the maximum amplitude value for each scale is a better predictor of known weights than either the DC amplitude or the FHF amplitude. Scale 1+2+3 maximum amplitude is the closest predictor of static weights, but on average, still predicts the weight of the animal 214 lbs lower than the known static weight.

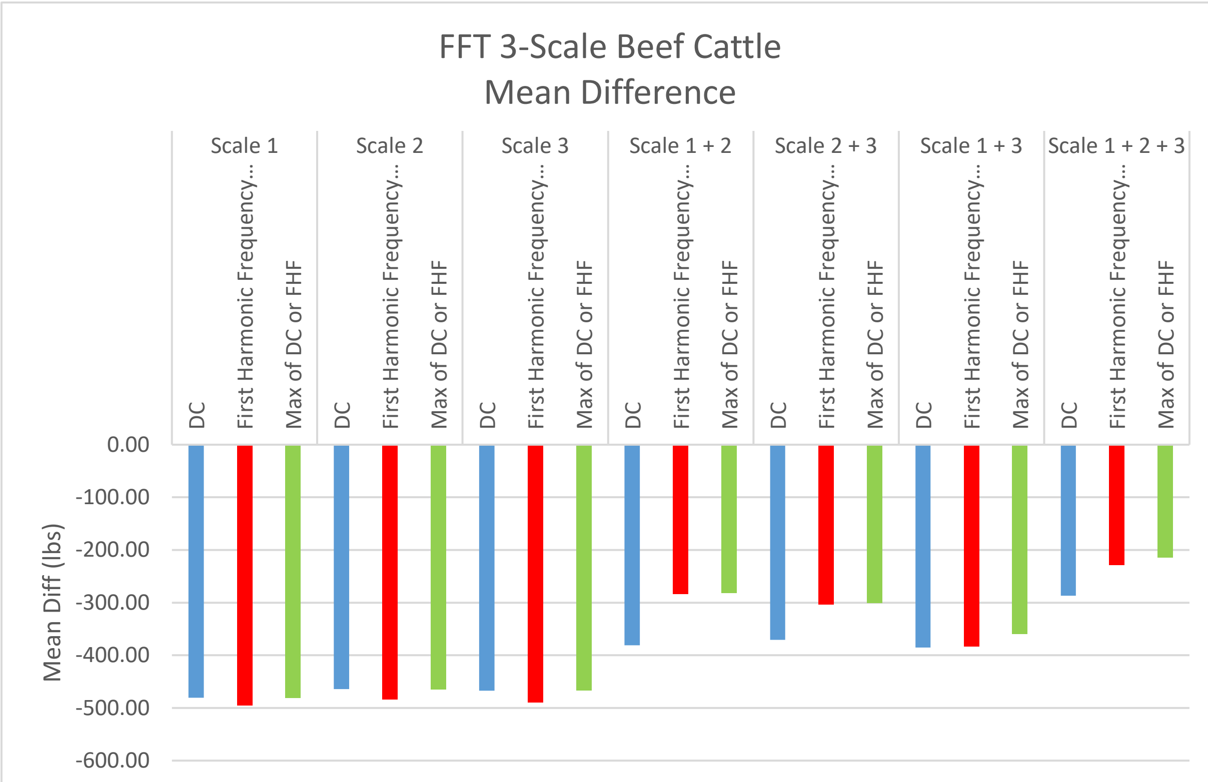


Figure 63 3-Scale Beef Cattle FFT Mean Difference.

The standard deviations of the differences for all scale combinations using the FFT analysis method in the 3-Scale Beef Cattle portion of this study range from 52 lbs to 82 lbs, with most of the standard deviations falling in between 60 lbs and 80 lbs (figure 64). The lowest standard deviation of the difference was the Max of DC or FHF amplitude value using the Scale1+2+3 combination (52.76 lbs).

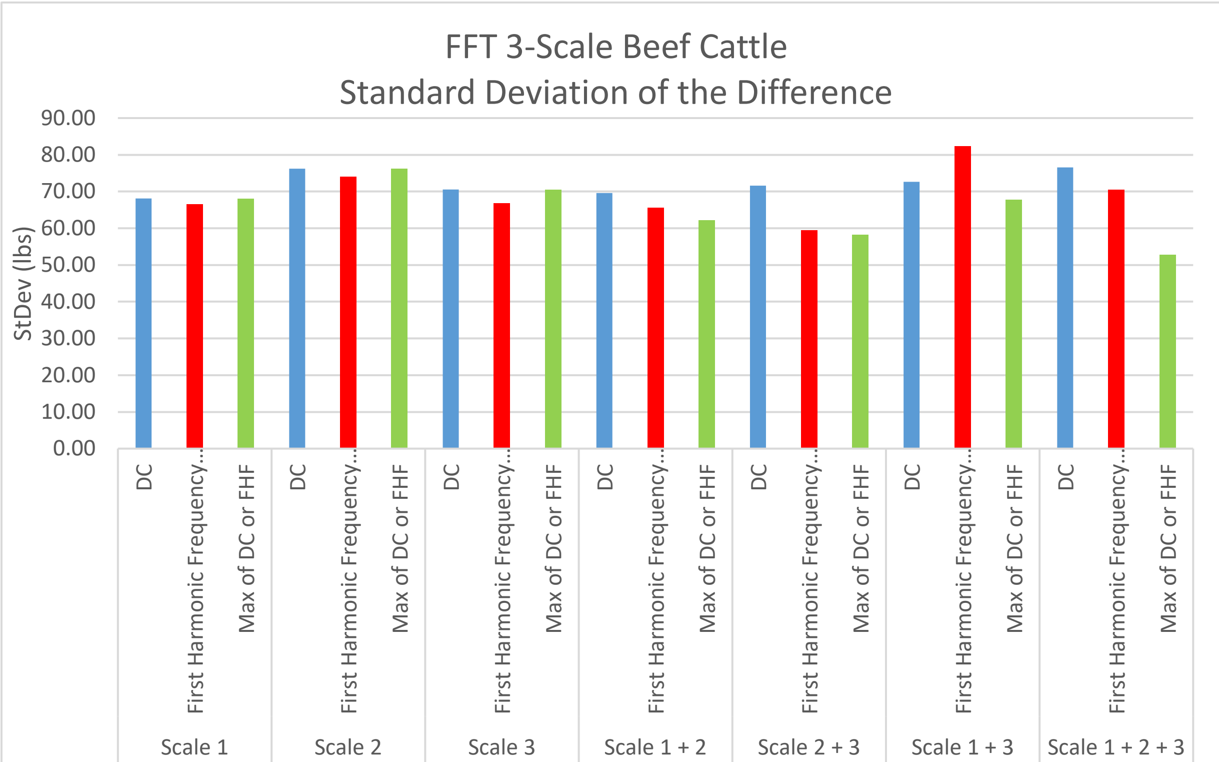


Figure 64 3-Scale Beef Cattle FFT StDev Difference.

Root Mean Square of Frequency Analysis Method

Statistical Analysis for Root Mean Square (RMS) analysis method for the 3 – Scale Beef Cattle portion of this study can be found in Appendix L.

The R-Squared Values for the RMS analysis method when applied to the 3-Scale Beef Cattle data sets, do not change significantly between weight thresholds for any scale combinations, but R-squared values do change significantly between combinations of scales. Scale 1+2, Scale 2+3, and Scale 1+2+3 are all about the same R-squared values with the RMS analysis method, however, individual scale and Scale 1+3 R-squared values are lower than the other combinations (figure 65). The highest R-squared value 0.67 when using the combination scales 1+2 and 1+2+3, with Scale 2+3 obtaining the second highest R-squared value of 0.64, all at a weight threshold of 1.0 lbs (Appendix L)

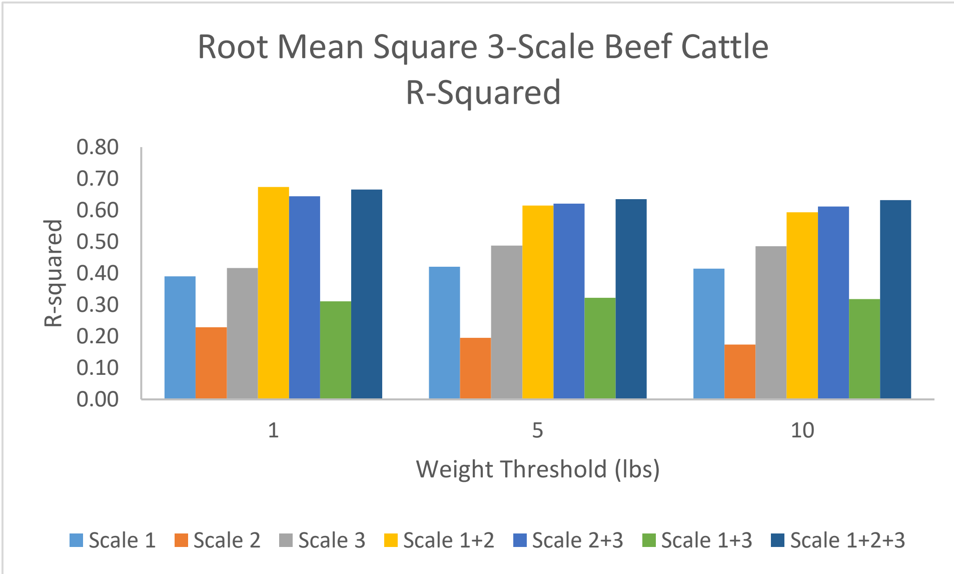


Figure 65 3-Scale Beef Cattle RMS R-Squared.

As with the other analysis methods, the predicted static weight of the cattle when using the RMS analysis method for the 3-Scale Beef Cattle portion of the study, is on average lower than the known static weight of the cattle. The mean differences when using the RMS analysis method does not change significantly with a change in weight threshold for any scale combination (figure 66). Scale 1+2+3 is the closest predictor of static weights for any weight threshold, followed by Scale 1+2, then Scale 2+3. Scale 1+2+3 has the lowest mean difference at -91.22 lbs (weight threshold of 10 lbs).

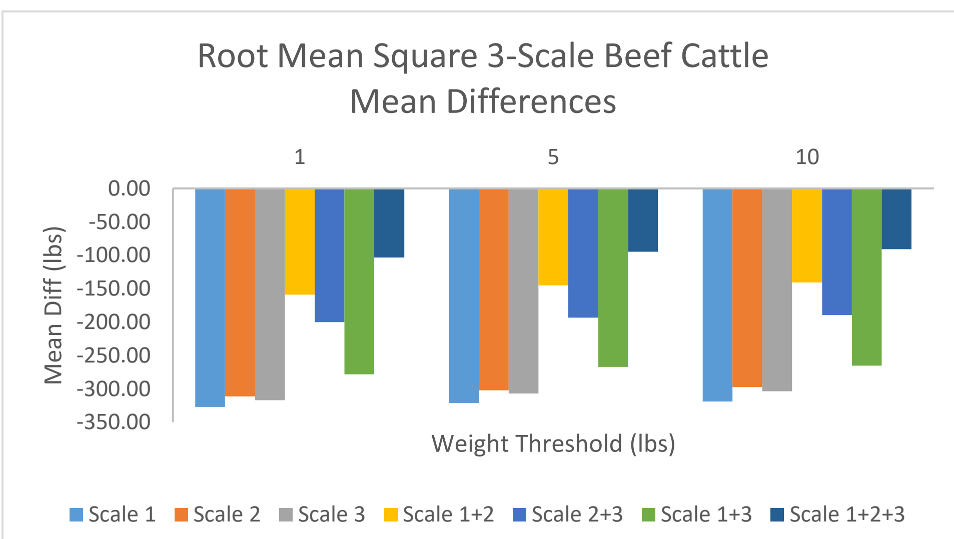


Figure 66 3-Scale Beef Cattle RMS Mean Difference.

The standard deviations of the differences are close to the same for the individual scales and Scale 1+3, as well as scale combinations 1+2, 2+3, and 1+2+3 across all weight thresholds (figure 67). Scale 1+2, Scale 2+3, and Scale 1+2+3 have the lowest standard deviations, with a range across all weight thresholds of 43.91 lbs to 48.91 lbs (Appendix L). This five pound difference falls close to the accuracy of the 3-Scale walkover platform (accuracy = 4.44 lbs).

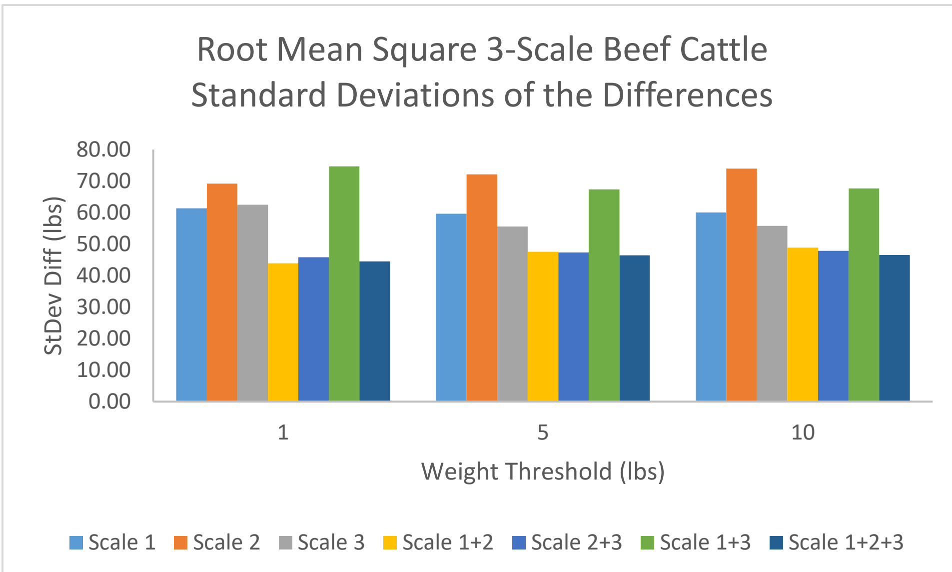


Figure 67 3-Scale Beef Cattle RMS StDev Differences.

Comparisons of Scale Combinations

In the 3-Scale Beef Cattle portion of this study, the highest R-squared values calculated was 0.68, Scale 1+2, SID analysis method, m threshold of 24, and Scale 3, SID analysis method, m threshold of 22. These R-squared values was followed by several 0.67 R-squared values; 1) Scale 1+2, SID analysis method, m threshold of 23, 2) Scale 1+2+3, AEB analysis method, weight threshold of 90 lbs, 3) Scale 1+2, RMS analysis method, weight threshold of 1.0 lbs, 4) Scale 1+2+3, RMS analysis method, weight threshold of 1.0 lbs. Generally, the more scales that are summed together in an analysis method, the greater the R-squared value, with the exception of the SID analysis method, where Scale 3 was the highest R-squared value followed by Scale 1+2. Figure 68, illustrates the general ability of the scale combinations to predict the static weight of the animals versus other scale combinations.

When comparing the mean differences between all scale combinations for each of the analysis methods, the closest mean difference to zero, which indicates that the average predicted weight is closest to the known static weights, was 4.39 lbs from Scale 1+2 using the AEB analysis method at a weight threshold of 350 lbs. Figure 68, makes the general comparisons for the mean difference for each scale over all analysis methods. Generally, Scale 1+2+3 has the highest mean difference closest to zero for most weight thresholds in each analysis methods. The only exception to Scale 1+2+3 having the mean difference closest to zero is weight thresholds above 350 lbs in the AEB analysis method. Generally, as illustrated in Figure 68, the more scales tha can be used in the data to predict static weight, the closer the average predicted weights are to the known static weights. It is not worthy that for many analysis methods, the mean difference for Scale 1+2+3, Scale 1+2, and Scale 2+3 are close together. Also, the mean differences for Scale 1+3, Scale 1, Scale 2, and Scale 3 are close together.

The standard deviation of the differences follow the same general trend as the R-squared comparisons of each scale combinations for the analysis methods. The one exception in analysis methods is the SID analysis method where Scale 3 has the lowest standarda deviation of the difference for most m thresholds and the other scale combinations switch orders as the m threshold increases, and Scale 1+2+3 has the highest standard deviation of the difference. The lowest standard deviation of the difference in the 3-Scale Beef Cattle portion of this study is 43.91 lbs found when using Scale 1+2 with the RMS analysis method at the 1.0 lbs threshold. It is important to note that, in general, the RMS analysis method has the lowest standard deviation of the differences for the scale combinations, particularly with Scale 1+2, Scale 2+3, and Scale 1+2+3, where the entire range of standard deviation of the differences is 43.91 lbs to 48.91 lbs. A five pound difference for three scale combinations over three weight thresholds.

R-squared

Scale 2 < Scale 1 < Scale 1+3 < Scale 3 < Scale 1+2 < Scale 2+3 < Scale 1+2+3

Mean Difference

Scale 1 < Scale 2 < Scale 3 < Scale 1+3 < Scale 2+3 < Scale 1+2 < Scale 1+2+3

Standard Deviation of the Difference

Scale 2 < Scale 1 < Scale 1+3 < Scale 3 < Scale 1+2 < Scale 2+3 < Scale 1+2+3

Figure 68 3-Scale Beef Scale Accuracy Rankings.

3-Scale Dairy Cattle

Successive Increase/Decrease in Data Values Analysis Method

Statistical Analysis for Successive Increase/Decrease in Data Values (SID) analysis method for the 3 – Scale Dairy Cattle portion of this study can be found in Appendix M.

The 3 scale dairy cattle portion of the study had generally low correlation values when using the SID analysis method for all scale combinations (Scale 1, Scale2, Scale 3, Scale 1+2, Scale 2+3, Scale 1+3, and Scale 1+2+3), with no correlation values for any scale combination being above 0.50 (figure 69). With the exception of Scale 3, the different combination of scales generally increase as the M Threshold increased. Scale 3 appears to have a more erratic correlation as the m threshold increases. Looking in Appendix M, Scale 3 has lower number of data sets used, than the other combinations of scales. This could be because the cattle tended to fall sideways off of scale 3, instead of exiting straight like the cattle in the 2-Scale and 3-Scale Beef. None the less, there does not appear to be any correlation (R-

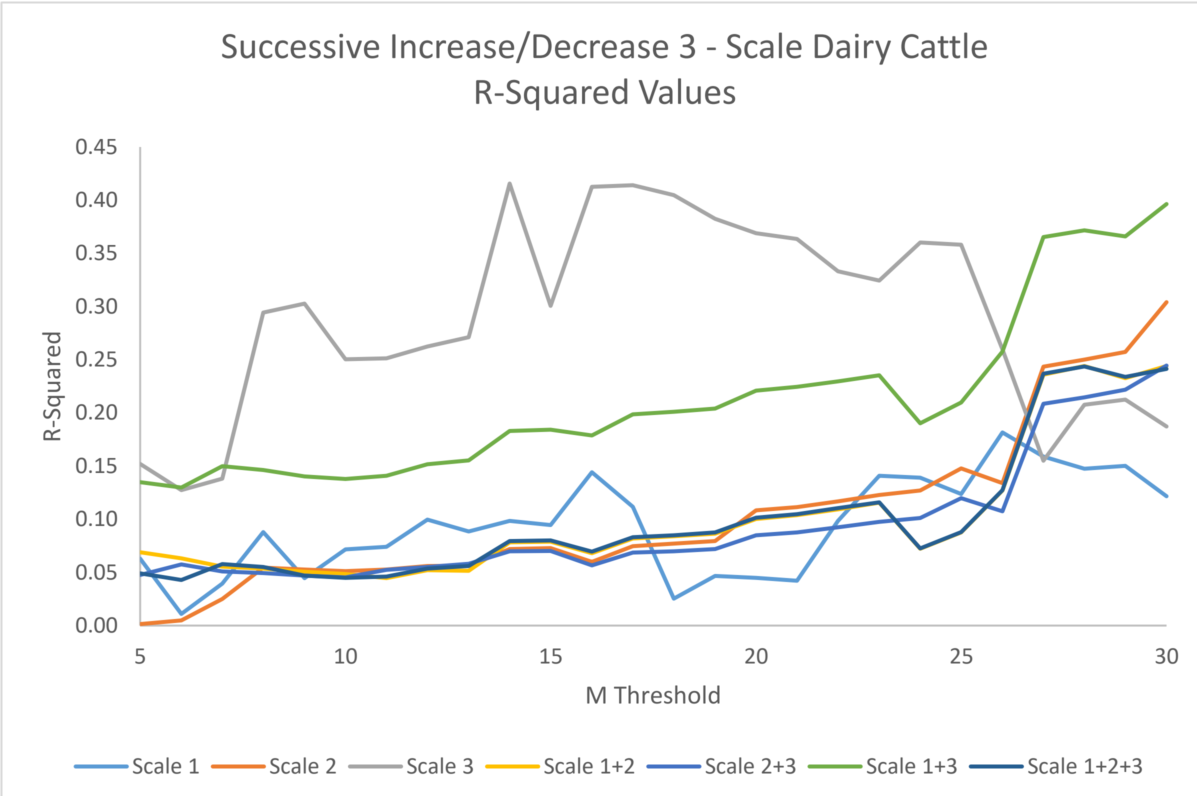


Figure 69 3-Scale Dairy Cattle SID R-Squared.

squared > 0.50) for any combination of scales for the 2-Scale Dairy Cattle portion of this study using the SID analysis method.

The mean difference between the predicted static weights and the known static weights of the animals in the 3-Scale Dairy Cattle portion of this study are significantly lower than the differences found in the 2-Scale and 3-Scale Beef Cattle portions of this study, when using the same analysis method. The predicted static weights of the animals were at least 900 lbs below their known static value with most predicted static weights being 1000 lbs below the known static value (figure 70). Even as the M Threshold increased, the predicted values stayed relatively constant for each of the scale combinations,

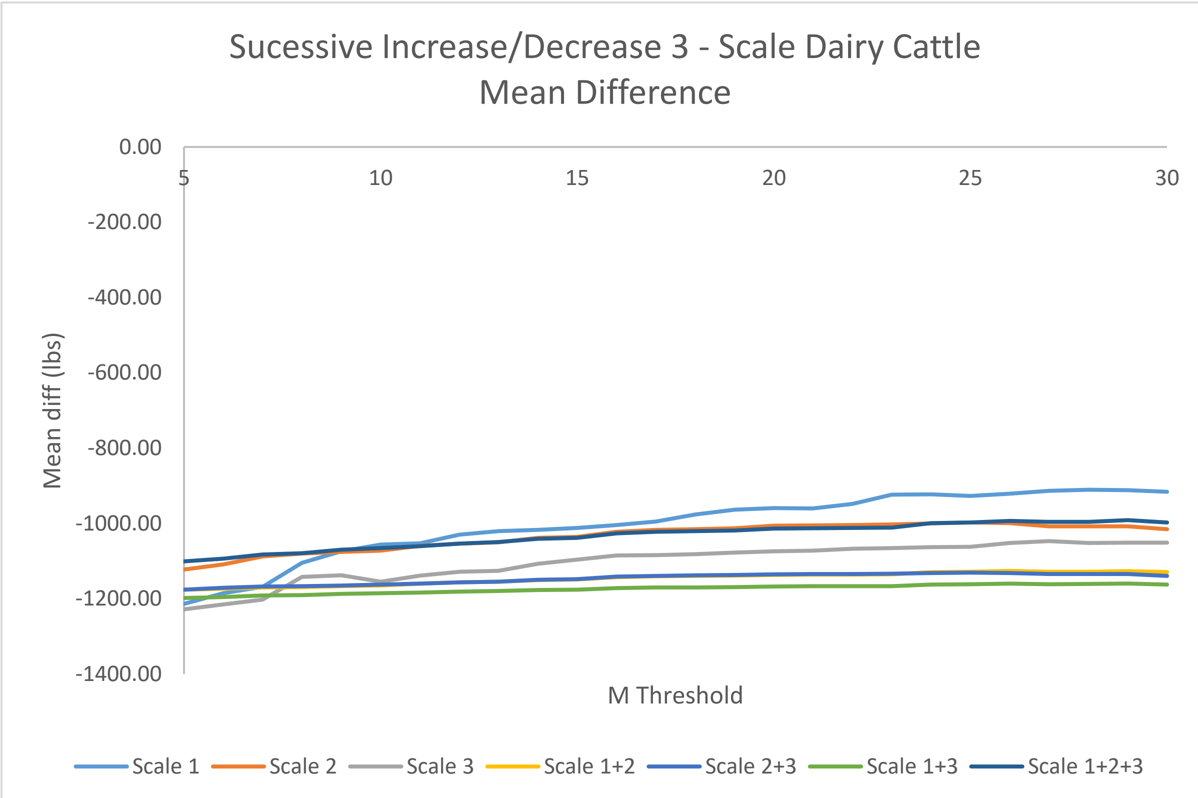


Figure 70 3-Scale Dairy Cattle SID Mean Difference.

with the exception of Scale 1, which say the mean differences in predicted static weight and known static weights becoming closer, but not close, to zero.

The 3-Scale Dairy Cattle portion of this study using the SID analysis method saw high standard deviation values when compared to the 2-Scale and 3-Scale Beef Cattle portion of this study. Most standard deviations were around 350 lbs (figure 71), with the notable exception of Scale 3, which had standard deviations around 350 lbs when the M Threshold was 5 lbs, but decreased as the m threshold increased, though only reaching a low standard deviation of the difference at 282.62 lbs (m threshold 14). Again, the dairy cattle were generally not on Scale 3 as long as Scale 1 and Scale 2, and the number of data sets when met the required M Threshold was less than the other scale combinations (Appendix M).

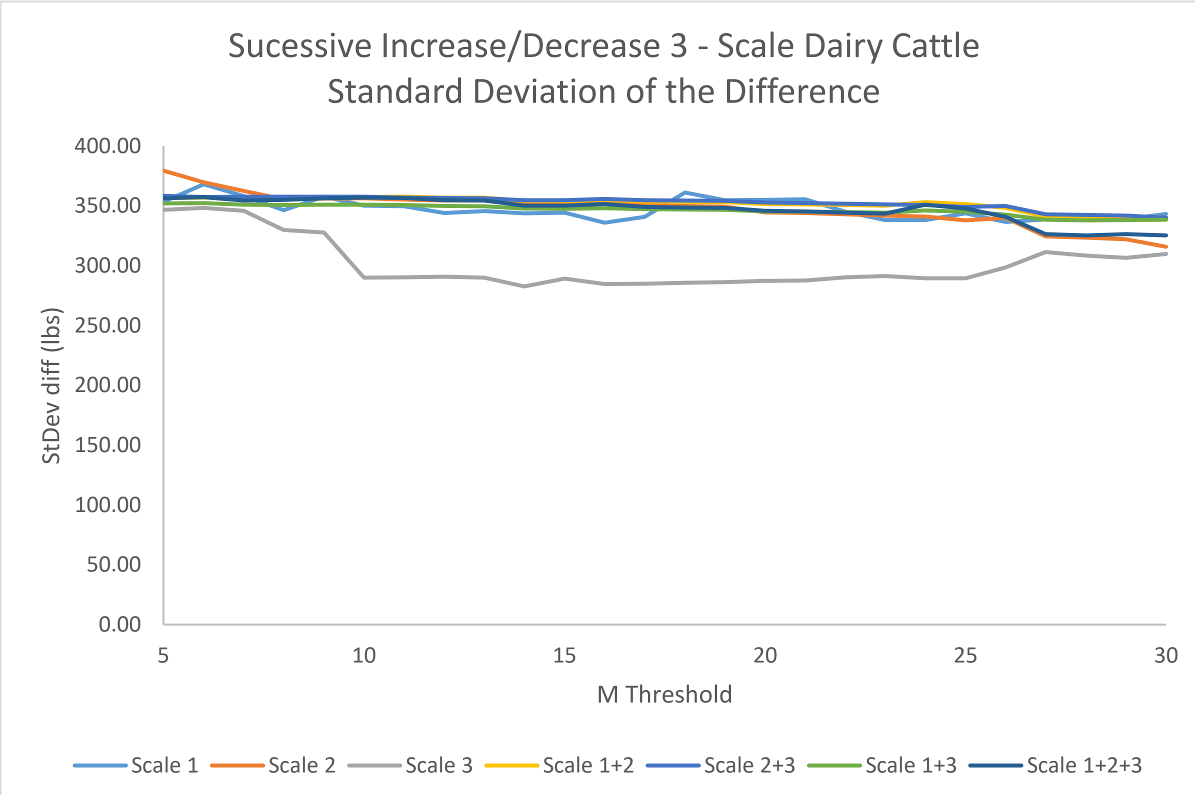


Figure 71 3-Scale Dairy Cattle SID StDev Difference.

Due to the low mean differences, and high standard deviations of the differences for the 3-Scale Dairy Cattle portion of this study, using the SID analysis method is probably not the best analysis method for these data sets.

Average Everything Between Analysis Method

Statistical Analysis for Average Everything Between (AEB) analysis method for the 3 – Scale Dairy Cattle portion of this study can be found in Appendix N

The 3-Scale Dairy Cattle generally have low R-squared values when using the AEB analysis method. Also, as seen with other portions of this study, the R-square values overall decrease as the weight threshold increases for the AEB analysis method. Illustrated in figure 72, the R-squared value for Scale 2 is the largest for all weight thresholds in which it is graphed, but even Scale 2's R-squared value is less than 0.50 indicating there is no linear correlation between the predicted static weights of the animal and their calculated static weight.

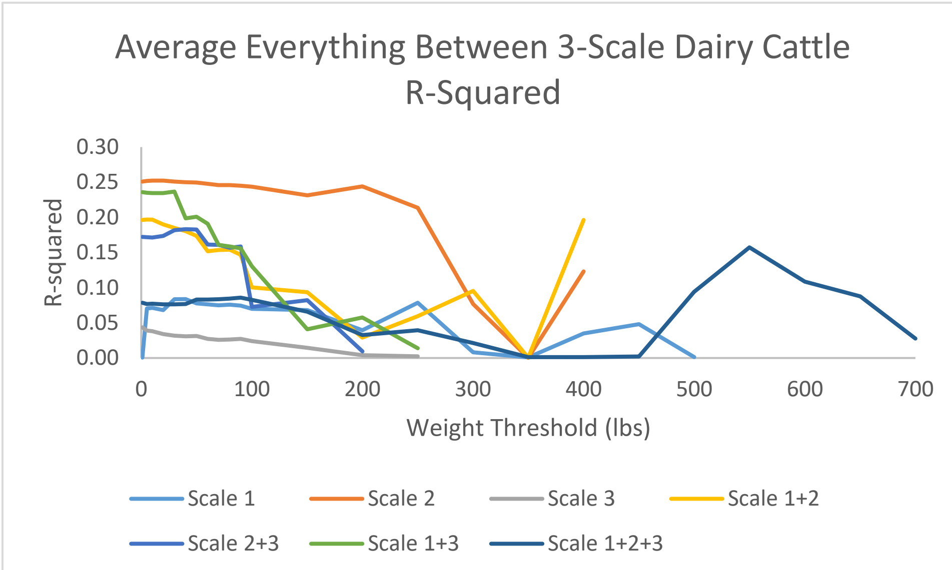


Figure 72 3-Scale Dairy Cattle AEB R-Squared.

The mean difference for the 3-Scale Dairy Cattle portion of the study, when using the AEB analysis method, generally increases (gets closer to zero) as the weight threshold increases, though the highest mean difference between the predicted static weights of the animal and their calculated static weight is -683.49 (Scale 1+2+3, weight threshold 700 lbs, figure 73).

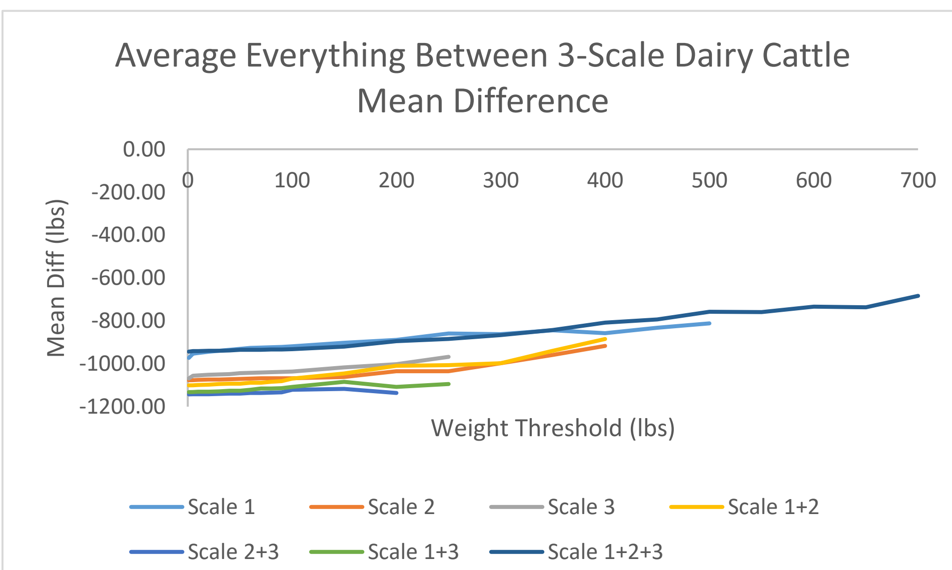


Figure 73 3-Scale Dairy Cattle AEB Mean Difference.

The standard deviation of the differences for the 3-Scale Dairy Cattle portion of this study are significantly higher than those of the 3-Scale Beef Cattle portion. The standard deviation of the differences between the predicted static weights of the animals and their calculated static weight holds fairly steady as the weight threshold increases (figure 74) Theses standard deviations of the differences indicate a wide range of predicted weights, with errors for 95% of the data being greater than 600 lbs from the mean predicted weight.

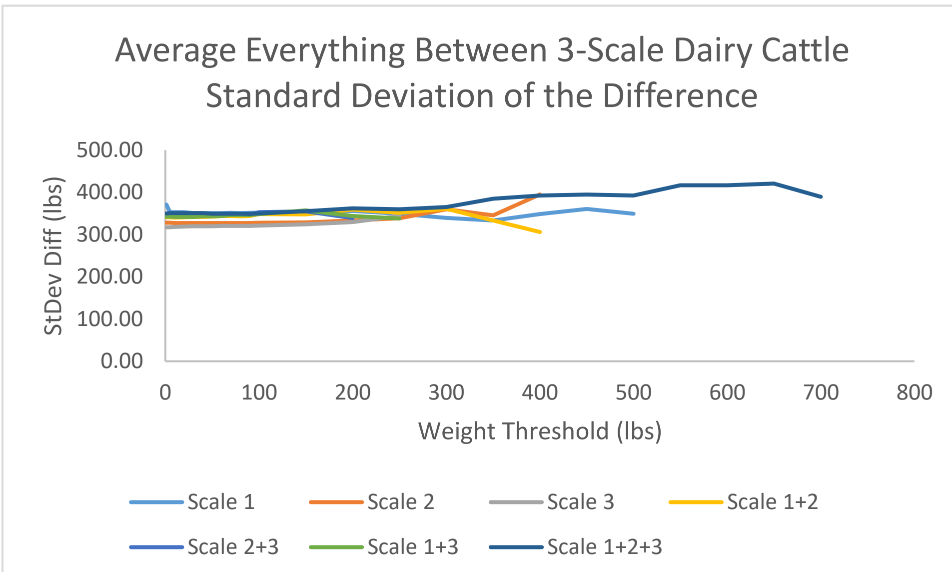


Figure 74 3-Scale Dairy Cattle AEB StDev Difference.

Fast Fourier Transform Analysis Method

Statistical Analysis for Fast Fourier Transforms (FFT) analysis method for the 3 – Scale Dairy Cattle portion of this study can be found in Appendix O.

When performing the FFT analysis method on the data sets from the 3-Scale Dairy Cattle portion of this study, calculated R-squared values were low. No R-squared value was above 0.07 with most being below an R-squared value of 0.05 (figure 75). This indicates there is no correlation between the predicted static weights of the animals and the calculated static weights of the Dairy cattle.

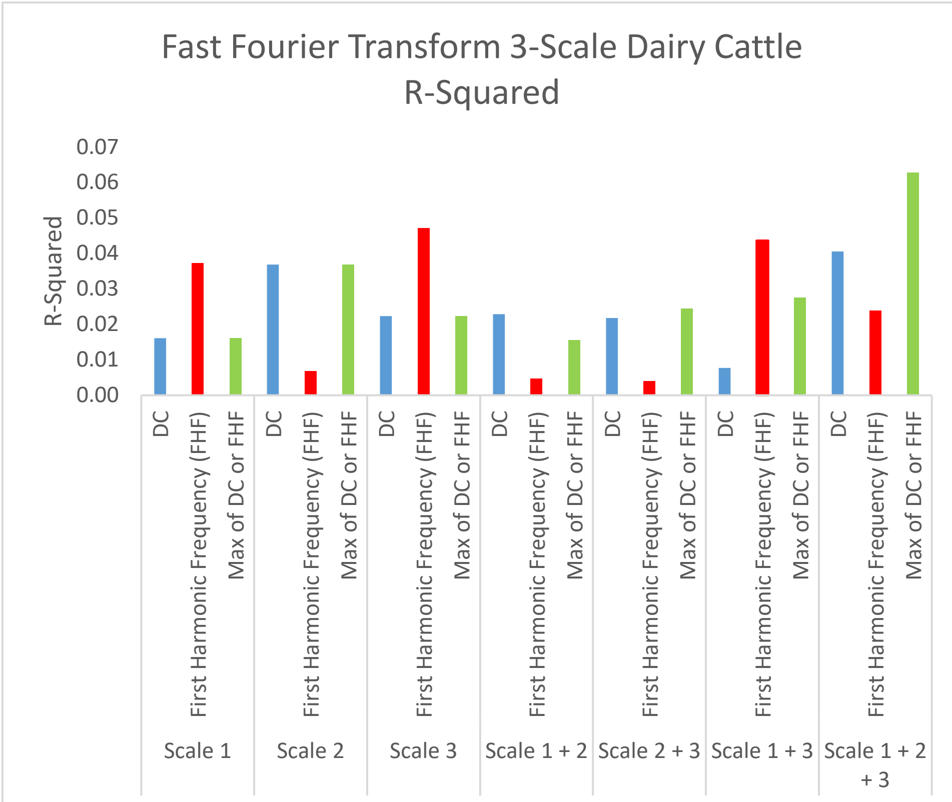


Figure 75 3-Scale Dairy Cattle FFT R-Squared.

Mean differences between the predicted static weights of the cattle and the calculated static weights were never above -1000 lbs (figure 76). Since some of the cattle only weight just above 1000 lbs, this analysis method seems to not be able to predict the static weight of animals.

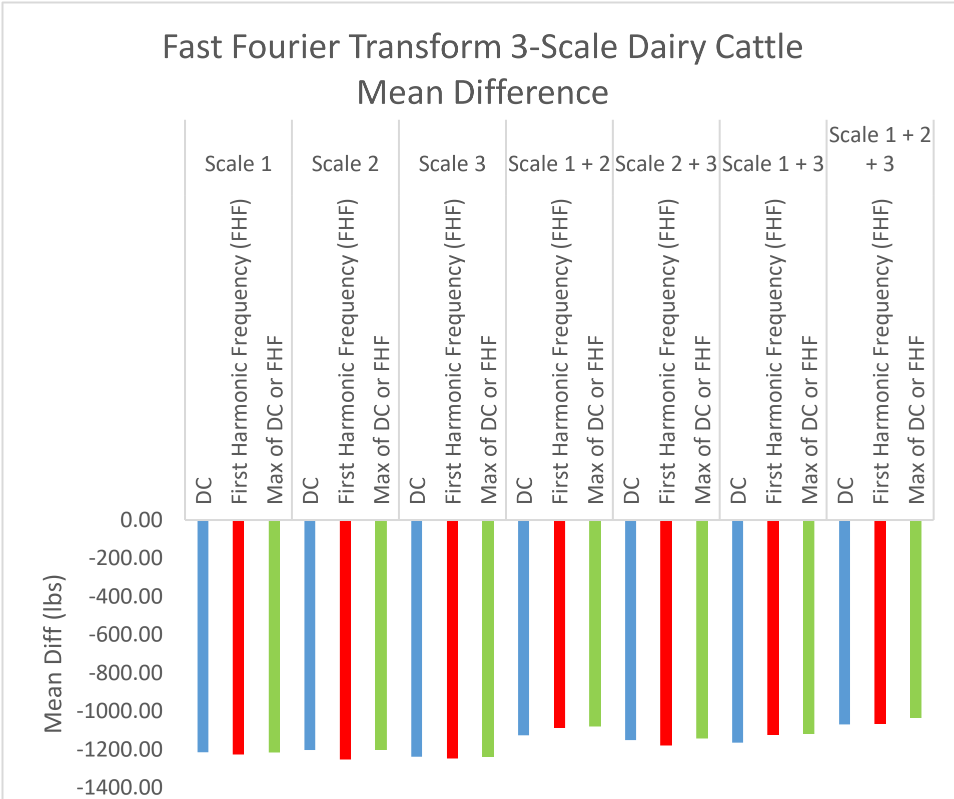


Figure 76 3-Scale Dairy Cattle FFT Mean Difference.

Standard deviations of the differences between the predicted static weight of the cattle and the calculated static weight were significantly higher than those of both the 3-Scale Beef Cattle portion of this study and the 2-Scale Beef Cattle portion of this study, when using the same FFT analysis technique. Standard deviations of the differences were at a minimum 263 lbs (Scale 3, FHF, figure 77). Most standard deviations of the differences ranges between 260 lbs and 275 lbs, indicating a consistent standard deviation of the difference for all scale combination when using the FFT analysis method in the 3-Scale Dairy Cattle portion of this study.

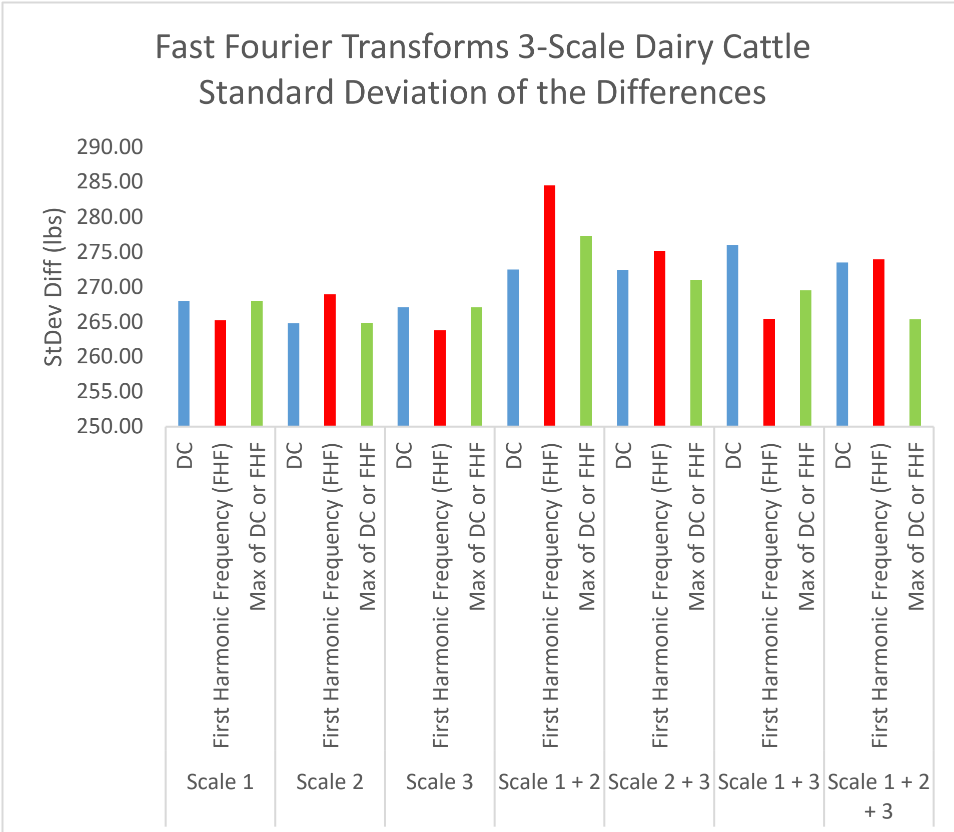


Figure 77 3-Scale Dairy Cattle FFT StDev Difference.

Root Mean Square of Frequency Analysis Method

Statistical Analysis for Root Mean Square (RMS) analysis method for the 3 – Scale Dairy Cattle portion of this study can be found in Appendix P.

The R-squared values in the 3-Scale Dairy Cattle portion of this study when using the RMS analysis method all fall below 0.30 for all scale combinations and weight thresholds. The R-squared values (with the exception of Scale 1) are held generally constant with increases in weight thresholds (figure 78). Scale 1, appears to be the different scale, as Scale 1's R-squared value at a weight threshold of 1.0 lbs is 0.06, but increases to 0.14 for weight thresholds of 5.0 lbs and 10 lbs. Scale 2 and the combination Scale 1+3 have the best R-squared values at each of the weight thresholds and are close to each other also.

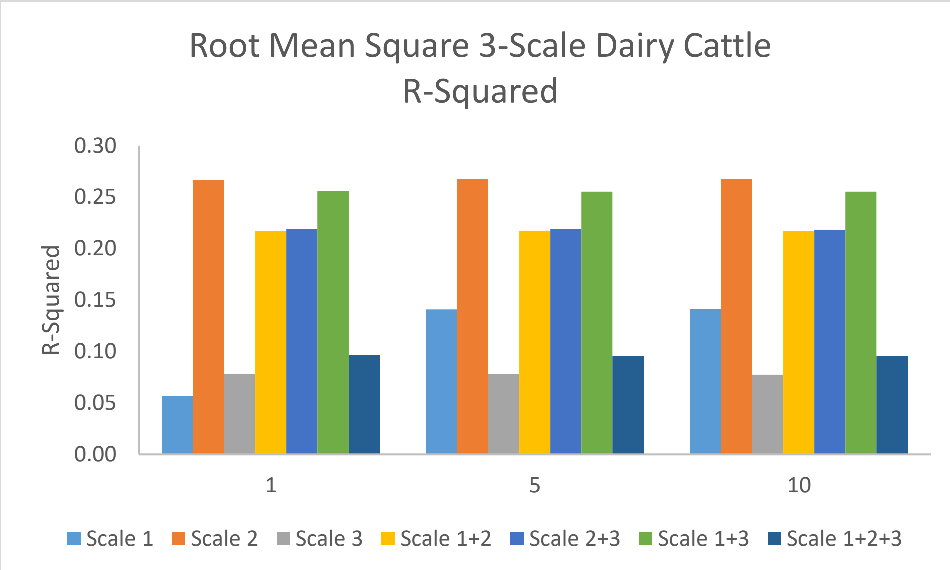


Figure 78 3-Scale Dairy Cattle RMS R-Squared.

The mean differences for the 3-Scale Dairy Cattle portion of this study, when using the RMS analysis method are better than the FFT analysis method, but still worse than the 2-Scale Beef Cattle and 3-Scale Beef Cattle portions of this study. The mean differences for each scale combination is generally consistent as the weight threshold increases, and the closest predictor of static weight is Scale 1+2+3 with a mean difference of -863.11 (weight threshold 10 lbs), as illustrated in figure 79. However, all scale combinations at all weight thresholds significantly under predict the static weight of the dairy cattle.

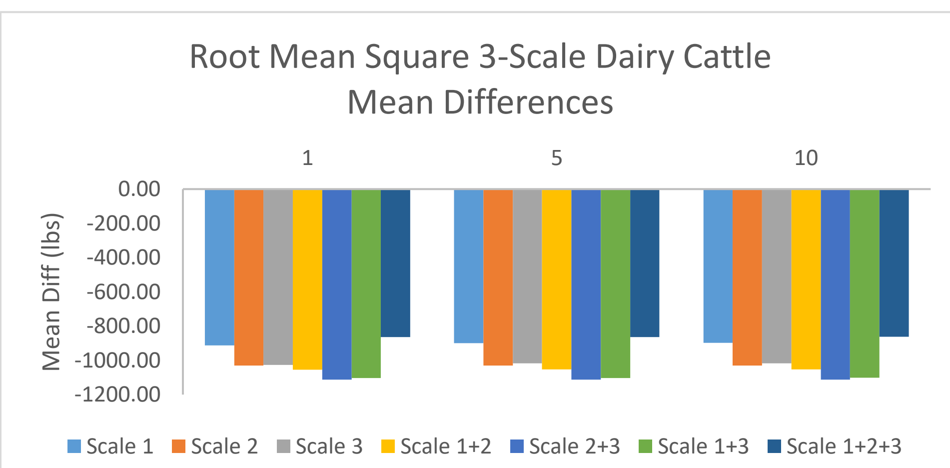


Figure 79 3-Scale Dairy Cattle RMS Mean Difference.

Standard deviations of the differences for the all scale combinations in the 3-Scale Dairy Cattle portion of this study, when using the RMS analysis method, range from 311.50 lbs (Scale 3, weight threshold 1.0 lbs) to 354.41 lbs (Scale 1, weight threshold 1.0 lbs).The standard deviations are consistent as the weight thresholds increase, and for combinations of scales 1+2, 2+3, 1+3, and 1+2+3, the standard deviations are close to each other (figure 80). These standard deviations, while consistent with other standard deviations of the 3-Scale Dairy Cattle, when using various analysis methods, are significantly higher than those of the 2-Scale and 3-Scale Beef Cattle portion of this study.

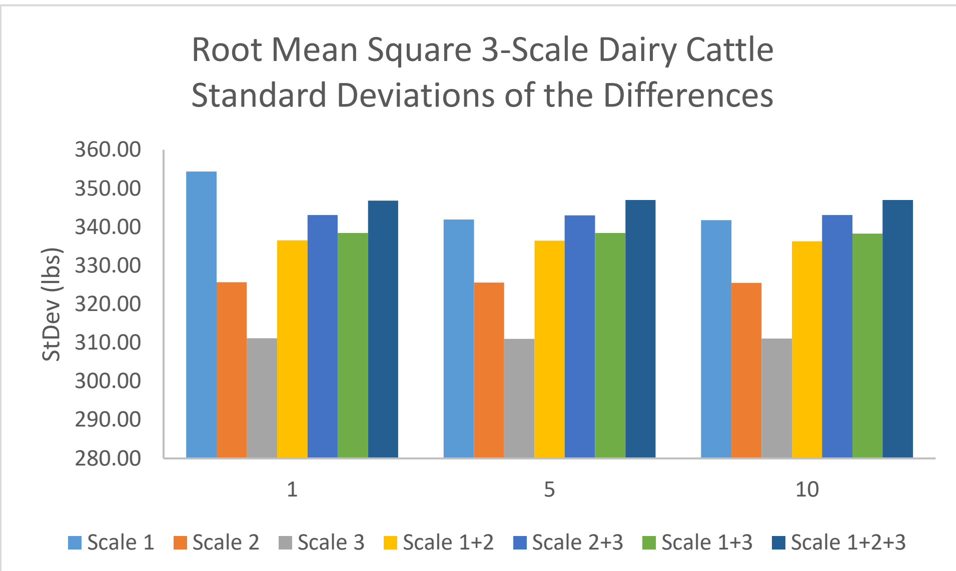


Figure 80 3-Scale Dairy Cattle RMS StDev Difference.

Comparisons of Scale Combinations

In the 3-Scale Dairy Cattle portion of the study, R-squared values for each of the scale combinations with each of the analysis methods follow a semi-consistent pattern. Generally, Scale 3 and Scale 1+3 have the highest R-squared values followed by Scale 1+2 and Scale 2+3, but not always. The highest R-squared value correlated was Scale 3 at an m threshold of 16 and 17 using the SID analysis method. R-squared values are relatively low when compared to the 2-Scale and 3-Scale Beef Cattle portions of this study, and the R-squared values from the FFT analysis method are the lowest of the analysis methods in the 3-Scale Dairy Cattle portion of the study.

As with the R-squared valued, the mean differences for the 3-Scale Dairy Cattle portion of the study vary with analysis method and do not follow a trend. All of the mean differences for the analysis methods are below zero indicating the average predicted weights for the dairy cattle are below their known weight. The highest mean difference is -683.49 lbs. This mean difference is Scale 1+2+3 data using the AEB analysis method at a weight threshold of 700 lbs.

The standard deviations of the difference are generally the same for each scale combination in each analysis method regardless of the threshold. As before, there is no particular trend when comparing the scale combinations standard deviations of the differences, as the "ranking" for each combination changes with analysis method.

Long et al Analysis Method

An attempt was made to use the Hamming window as proposed by Long et al, on the data sets, but an output was never obtained. Most of the analysis methods in this study were performed using Microsoft Excel. Microsoft Excel does not have the ability to perform Hamming windows on data sets, and attempts to use Matlab to perform Hamming windows did not work. Additionally, the Long et al study utilized the Hamming window of a digital signal converted from the analog signal produced at the load cells. The study did not take data from a digital signal, but rather the HX711 converted the digital signal to data values and sent the data values to the Arduino. Upon researching, the Hamming window's function, there was no clear way to perform the Hamming window on the data. Therefore, no data analysis was performed on the beef or dairy cattle data using a Hamming window, and none will be discussed in the findings section.

CHAPTER V

CONCLUSION

Limitations

The cattle used in this study were all from the same herd and their behavior was relatively similar (with some exceptions). Potentially different herds of cattle with different behaviors and genetics could affect the predictions of the multi-scale walkover platform. Additionally, less than one-hundred walkover data sets were used in this study, and more data sets could provide a greater insight into predictions of static weights with the various analysis methods.

Conclusions

Knowing the approximate weight of each animal in a livestock operation is vital to the health of the animal and the health of the business. Stocker cattle operations are a large part of the Oklahoma beef cattle economy as well as the beef cattle industry as a whole. Precision Livestock Management attempts to bring technology and data to these types of operations. Since weight is a primary driving force in any stocker operation, it is important for owners and operators to constantly and effectively monitor the weight of an animal. Walkover scales provide a useful tool in assisting the weight monitoring process, but most walkover scales are a single walkover scales. The attempt of this study was to determine the ability of a multi-scale walkover system to: 1) predict the weight of the cattle using a series of scales, 2) predict the weight of cattle using single scales, or a combination of scales, and 3) predict individual cattle weight during crowding events on a scale system.

Previous research suggests that a minimum of 1.8m long scale is necessary to accurately predict the static weight of an animal from its' dynamic walkover weight, and that a sampling rate of at least 20 Hz is necessary to predict the static weight. Data analysis methods were performed on each scale individually, and all possible combinations of scales. Several different types of data analysis were performed on the data sets. The basis for each type of data analysis (with the exception of FFTs) was to average data points in the data sets and predict the static weight of the animal from this average. However, each data analysis method differed in their determination of when to start and stop the data array for averaging varied. FFTs were unique in that this type of data analysis analyzed the data points for recurring frequencies in the data set. All static weight predictions were compared against their known static weight, to determine accuracy of the analysis method.

To accurately predict the static weight of the cattle, a three step analysis method of the data is required. First, a moving average of the raw data must be computed, second, an analysis method is applied to the moving average data (except FFTs where it used raw data), and lastly, either the linear R-squared equation (equation 16) of a line is used, or a weight shift of the graph must be used by the amount of the mean difference.

In the 2-Scale Beef Cattle portion of the study, using the Average Everything Between analysis method on Scale 1+2 was the best predictor of static weights. Specifically, the lower weight thresholds yielded better standard deviations than the higher weight thresholds.

In the 3-Scale Beef Cattle portion of the study, Root Mean Squared analysis method was slightly better than the Average Everything Between analysis for their R-squared values, mean differences, and standard deviations of the differences for comparable weight thresholds. The difference in R-squared, mean difference, and standard deviation of the difference are potentially statistically insignificant and may vary depending on behavior of cattle, as well as weight ranges outside of the cattle used in this study.

In the 3-Scale Dairy Cattle portion of the study, no particular analysis method was better at predicting the static weight than another. As previously mentioned, each analysis method had low R-squared values, large differences in predicted static weights and calculated static weights (mean differences), and high standard deviations.

The best predictor of static weights in this study was the combination of scales 1+2, 2+3, and 1+2+3 in the 3-Scale Beef Cattle portion of this study using the Root Mean Square (RMS) of the Frequency analysis method, because the R-squared values were the highest of all scale combination and analysis methods, and the standard deviations were the lowest of all scale combinations and analysis methods. Scale 1+2 in the 2-Scale Beef Cattle portion of this study when using the Average Everything Between analysis method at weight thresholds of 90 lbs or 100 lbs was a close runner-up, and could potentially be a viable way of predicting static weights. It is not surprising that three scales has a slight edge when predicting static weights over two scales, because three scales measures dynamic weight data for a longer distance. As mentioned in Long et al. 1991, Ren et al. 1992, and Peiper et al 1993, a walkover scale has to long enough to collect enough walkover data to predict the static weight accurately, but be short enough to avoid crowding events.

1. Can a series of walkover scales be used to predict the static weight of an animal from their dynamic walkover weight?
    - Yes, a series of walkover scales can be used to predict the static weight of an animal from their dynamic walkover weight. As this study has demonstrated,

various analysis methods used on various scale combinations can predict the static weight.

2. How many scales are required for accurate prediction?
    - Technically, single scale walkover systems can accurately predict the static weight of cattle, however, multiple scales are used as a means of separating walkover weight data during crowding events. At which point, a minimum of two scales are required to predict the static weight of cattle with three scales providing a more accurate prediction.
3. Can cattle weights be separated during crowding events using multiple scales?
    - Yes, since the static weight of cattle can be predicted from the dynamic walkover weight of cattle, theoretically, cattle weights can be separated. To separate the cattle weight of data, monitoring center of mass for the front and back half of the animal over the entire platform is necessary. The animal, in concept, should move in a single overall direction over the platform, and the center of mass should move with it. If the center of mass for the back half of an animal moves backwards quickly, as the front half of the same animal stays still, there is potentially another animal on the same scale, at which point walkover data should stop being collected for both animals until the animal separate.

Preliminary data suggests that the center of mass for both the front and back half of the animal could be approximated using the individual load cells at each corner of each scales and by using equations 15 and 16. The center of mass calculations could be used to track an animal through the multi-scale walkover platform and potentially through part of the Portable Automate Sorting System (PASS).

Lastly, when designing PASS to accommodate failure, three scales is likely the best option for because the combination of Scale 1+2 or Scale 2+3 could be used if either Scale 1 or Scale 3 is rendered unable to collect data. So long as Scale 2 can collect data, PASS can collect the dynamic walkover weight data of cattle and predict their static weight. However, building and maintaining three scales could be costly and price PASS out of the beef cattle technology market, at which point two scales is the best option.

REFERENCES

24-Bit Analog-to-Digital Converter (ADC) for Weigh Scales. (n.d.). AVIA. Retrieved from file:///E:/00 Thesis work/Thesis documents/Literature/Walkover scales/HX711_Data_Guide.pdf

Adafruit Metro Mini 328 https://wsww.adafruit.com/product/2590

Alawneh, J. I., Stevenson, M. A., Williamson, N. B., Lopez-Villalobos, N., & Otley, T. (2011). Automatic recording of daily walkover liveweight of dairy cattle at pasture in the first 100 days in milk. *Journal of Dairy Science*, *94*(9), 4431–4440. http://doi.org/10.3168/JDS.2010-4002

ASAE. (1985). Dimensions of Livestock and Poultry. ASAE. Retrieved from https://elibrary.asabe.org/standards.asp

Bodge. (n.d.). HX711.

Broocks, A., Rolf, M., & Place, S. (2017, March). *Corn as Cattle Feed vs. Human Food*. Retrieved from http://factsheets.okstate.edu/documents/ansi-3296-corn-as-cattle-feed-vs-human-food/

Budynas, R. G, Nisbett, J. Keith, & Shigley, J. Edward. (2015). *Shigley's mechanical engineering design.* 10th ed. New York: McGraw-Hill.DB Browser for SQLite. (2007). Retrieved August 5, 2018, from https://sqlitebrowser.org/dl/

Dickinson, R. A., Morton, J. M., Beggs, D. S., Anderson, G. A., Pyman, M. F., & Mansell, P. D. (2013). An automated walk-over weighing system as a tool for measuring liveweight change in lactating dairy cows. *Journal of Dairy Science*, *96*(7), 4477–4486. http://doi.org/10.3168/jds.2012-6522

Filby, D. E., Turner, M. J. B., & Street, M. J. (1979). A Walk-through Weigher for Dairy Cows, (September 1978), 67–78.

González-garcía, E., Alhamada, M., Pradel, J., Douls, S., Parisot, S., & Bocquier, F. (2018). Original papers A mobile and automated walk-over-weighing system for a close and remote monitoring of liveweight in sheep. *Computers and Electronics in Agriculture*, *153*(August), 226–238. http://doi.org/10.1016/j.compag.2018.08.022

González-García, E., Golini, P. D. O., Hassoun, P., Bocquier, F., Hazard, D., González, L. A., … Greenwood, P. L. (2017). An assessment of Walk-over-Weighing to estimate short-term individual forage intake in sheep. *Animal*, 1–8. http://doi.org/10.1017/S1751731117002609

Gonzalez, L. A., Bishop-Hurley, G., Henry, D., & Charmley, E. (2014). Wireless sensor networks to study , monitor and manage cattle in grazing systems. *Animal Production Science*, *54*, 1687–1693.

Johnson, R. J., Doye, D., Lalman, D. L., Peel, D. S., & Raper, K. C. (2008). Adoption of Best Management Practices in Stocker Cattle Production. Stillwater, OK.

LOAD CELL WIRING. https://cdn.sparkfun.com/assets/learn_tutorials/3/8/3/Wheatstone-Bridge-02.jpg

Long, J., Takahata, H., Umetsu, K., Hoshiba, H., & Takeyama, I. (1991). A Livestock Walk-through Scale System, (11), 33–40.

Maltz, E., Kroll, O., Spahr, S. L., Devir, S., & Sagp, R. (1991). Milk Yield, Parity, and Cow Potential As Variables for Computerized Concentrate Supplementation Strategy, *74*, 2277–2289. http://doi.org/10.3168/jds.S0022-0302(91)78400-2

Microsoft(a). (n.d.). LINEST function. Retrieved from https://support.office.com/en-us/article/linest-function-84d7d0d9-6e50-4101-977a-fa7abf772b6d

Microsoft(b) (n.d.) TREND function. Retrieved from https://support.office.com/en-us/article/trend-function-e2f135f0-8827-4096-9873-9a7cf7b51ef1

Mcgrann, J. (2007). The United States Beef Cattle Industry : Production , Structure and Trends Prepared by. Texas A&M Agrilife.

Omega. (n.d.). Heavy Duty Shear Beam Load Cells. OMEGA. Retrieved from https://www.omega.com/pressure/pdf/LCJA.pdf

Peel, D. S. (2003). Beef cattle growing and backgrounding programs. *The Veterinary Clinics Food and Animal Practice*, *19*, 365–385. http://doi.org/10.1016/S0749-0720(03)00032-X

Peiper, U. M., Edan, Y., Devir, S., Barak, M., & Maltz, E. (1993). Automatic Weighing of Dairy Cows. *Journal of Agricultural Engineering Research*, *56*(1), 13–24. http://doi.org/10.1006/JAER.1993.1057

Ren, J., Buck, N. L., & Spahr, S. L. (1992). A DYNAMIC WEIGHT LOGGING SYSTEM FOR DAIRY COWS, *35*(April), 719–725.

Tru-Test. (n.d.). *2.5m WOW Cattle Platform*. Retrieved April 28, 2019, from https://livestock.tru-test.com/en/load-bars-cells/mp600

Tru-Test. (n.d.). *MP600*. Retrieved April 28, 2019, from https://livestock.tru-test.com/en/load-bars-cells/mp600

SPARKFUN LOAD CELL AMP (Top side) https://www.sparkfun.com/products/13879

SPARKFUN LOAD CELL AMP (Bottom side) https://www.sparkfun.com/products/13879

Wang, N. (2018). *Chapter 2 Signals – Static and Dynamic Characteristics*

Wende, A., & N. Seidle. (2016). SparkFun_HX711_Load_Cell_v11. Sparkfun. Retrieved from file:///E:/00 Thesis work/Thesis documents/Literature/Walkover scales/SparkFun_HX711_Load_Cell_v11_Schematic.pdf

Wishart, H., Morgan-davies, C., Stott, A., Wilson, R., & Waterhouse, T. (2017). Liveweight loss associated with handling and weighing of grazing sheep. *Small Ruminant Research*, *153*(March), 163–170. http://doi.org/10.1016/j.smallrumres.2017.06.013

APPENDICIES

APPENDIX A

#ARDUINO CODE INDIVIDUAL LOAD CELL CALIBRATIONS (get calibration factor)

```
#include "HX711.h"

#define DAT  4
#define CLK  2

HX711 scale(DAT, CLK);

float calibration_factor = -2050; //-7050 worked for my 440lb max scale setup

void setup() {
  Serial.begin(9600);
  Serial.println("HX711 calibration sketch");
  Serial.println("Remove all weight from scale");
  Serial.println("After readings begin, place known weight on scale");
  Serial.println("Press + or a to increase calibration factor");
  Serial.println("Press - or z to decrease calibration factor");
  scale1.begin(DAT, CLK);

  scale.set_scale();
  scale.tare(); //Reset the scale to 0

  long zero_factor = scale.read_average(); //Get a baseline reading
  Serial.print("Zero factor: "); //This can be used to remove the need to tare the scale. Useful in
permanent scale projects.
  Serial.println(zero_factor);
}

void loop() {

  scale.set_scale(calibration_factor); //Adjust to this calibration factor
```

```
  Serial.print("Reading: ");
  Serial.print(scale.get_units(), 1);
  Serial.print(" lbs"); //Change this to kg and re-adjust the calibration factor if you follow SI units like a
sane person
  Serial.print(" calibration_factor: ");
  Serial.print(calibration_factor);
  Serial.println();

  if(Serial.available())
  {
    char temp = Serial.read();
    if(weight == '+' || weight == 'a')
      calibration_factor += 100;
    else if(weight == '-' || weight == 'z')
      calibration_factor -= 100;
  }
}
```

APPENDIX B

#ARDUINO CODE BEEF CATTLE

Comment in and out calibration factors to correspond the load cell you are working on. Each calibration factor corresponds to a load cell (ex: factor1 = LC1).

```
#include <HX711.h>
#include <SoftwareSerial.h>

HX711 scale;

//float calibration_factor1 = 6268; //-7050 worked for my 440lb max scale setup
//float calibration_factor2 = 6387; //-7050 worked for my 440lb max scale setup
//float calibration_factor3 = 6016; //-7050 worked for my 440lb max scale setup
//float calibration_factor4 = 6025; //-7050 worked for my 440lb max scale setup
//float calibration_factor5 = 6061; //-7050 worked for my 440lb max scale setup
//float calibration_factor6 = 5571; //-7050 worked for my 440lb max scale setup
//float calibration_factor7 = 6316; //-7050 worked for my 440lb max scale setup
//float calibration_factor8 = 5774; //-7050 worked for my 440lb max scale setup
//float calibration_factor9 = 6540; //-7050 worked for my 440lb max scale setup
//float calibration_factor10 = 6245; //-7050 worked for my 440lb max scale setup
//float calibration_factor11 = 6360; //-7050 worked for my 440lb max scale setup
//float calibration_factor12 = 6100; //-7050 worked for my 440lb max scale setup

//int iterations = 0;

void setup()
{
  Serial.begin(9600);

  scale.begin(4,2);

//  scale.set_scale(calibration_factor1);
//  scale.set_scale(calibration_factor2);
//  scale.set_scale(calibration_factor3);
//  scale.set_scale(calibration_factor4);
//  scale.set_scale(calibration_factor5);
//  scale.set_scale(calibration_factor6);
//  scale.set_scale(calibration_factor7);
//  scale.set_scale(calibration_factor8);
//  scale.set_scale(calibration_factor9);
//  scale.set_scale(calibration_factor10);
//  scale.set_scale(calibration_factor11);
//  scale.set_scale(calibration_factor12);

  scale.tare();
```

```
}

void loop()
{

  Serial.println(scale.get_units(), 2); //scale.get_units() returns a float, value "2" is number of decimal
places
}
```

APPENDIX C

#ARDUINO CODE 3 SCALE DAIRY CATTLE

```
#include <HX711.h>
#include <SoftwareSerial.h>

/* Informs the Arduino that we want to use the HX711 library with the variable "scale"*/
HX711 scale;

void setup()
{
  /*Uses the library "SoftwareSerial" to send information at a BAUD rate of 9600*/
  Serial.begin(9600);

/* The variable scale begins reading pinouts 4 and 2. Pinout is scale.begin(DAT, CLK)*/
  scale.begin(4,2);

}

void loop()
{
/*sends the data from variable scale, function "read" through the serial port*/
  Serial.println(scale.read());
}
```

APPENDIX D

#Thread 1 PYTHON RECORD ALL LOAD CELLS

```
import sqlite3
import os
from os.path import expanduser
from os.path import exists
import serial
import time
from threading import Thread
from queue import Queue
from PASS_camera import Camera as Cam


class PASS(object):
  def __init__(self, **kwargs):

    #Use command prompt to ask user for database name
    # self.database_name = input("Which database would you like to use to store current data? ")
    #Database name for lab testing database connection.
    self.database_name = "Dairy Cattle Walkover Testing"
    #Database name for cattlewalk over database connection.
    # self.database_name = "Walkover_data_Repeatability_2.2"

    #Use command prompt to ask user for table name
    self.table_name_for_sqlite = input("What would you like the name of the table to be? ")
    # self.table_name_for_sqlite = "qwer"

    #Unsupportted cahracters for table names in sqlite3
    self.no_no_characters = ["-", "*", "/", "|", "<", ">",",", "=", "~", "!", "^", "(", ")", ";"]
    self.no_no_characters_list = '  '.join(self.no_no_characters)

    #Create serial connection variable
    ser1 = serial.Serial('COM20', 9600, timeout=1) #LC11 switched LC1 spot
    ser2 = serial.Serial('COM27', 9600, timeout=1)
    ser3 = serial.Serial('COM19', 9600, timeout=1)
    ser4 = serial.Serial('COM16', 9600, timeout=1)
    ser5 = serial.Serial('COM18', 9600, timeout=1)
    ser6 = serial.Serial('COM17', 9600, timeout=1)
    ser7 = serial.Serial('COM26', 9600, timeout=1)
    ser8 = serial.Serial('COM21', 9600, timeout=1)
    ser9 = serial.Serial('COM22', 9600, timeout=1)
    ser10 = serial.Serial('COM24', 9600, timeout=1)
    ser11 = serial.Serial('COM23', 9600, timeout=1)
    ser12 = serial.Serial('COM25', 9600, timeout=1)
```

```
    # ~ is the python default for starting at the current users folder
    self.p = expanduser('~')

    #Create boolean for data collection and ending data collection statements
    self.data_collection_statement = False

    #Create queue for loadcell data to be entered into and processed from
    self.data_queue = Queue()

    self.name_queue = Queue()

    self.com_port_list = [ser1, ser2, ser3, ser4, ser5, ser6, ser7, ser8, ser9, ser10, ser11, ser12]

    #Create self.serial_data array
    self.serial_data = []

    #Create array for sqlite table name info
    self.sqlite_table_name = []

    #Create array of LC data for kivy
    self.scale_info = []

    #Every 80th set of data intsert into array for kivy to use
    self.itterations = 0

def Arduino_data(self):
    try:
        while True:
            try:

                for i in self.com_port_list:

                    #Use with data input through serial port
                    data = i.readline()

                    # decode the byte string
                    data = data.decode()
                    # print(data)
                    data = data.strip('\r\n')

                    self.serial_data.insert(11,data)


                # print(self.serial_data)

                # self.serial_data = []
```

```
            #Only send data array to queue if quantity of values equals 12
            if len(self.serial_data) == 12:

                t = time.time()


                #insert time into data array. "0" is the position in the data array. "t" is the time
                self.serial_data.insert(0, t)

                #insert data array into queue
                self.data_queue.put(self.serial_data)

                self.itterations += 1

                # if self.itterations == 40:
                #     print(self.serial_data)

                #     self.itterations = 0
                #     # print(data)
                #     # print("I in data")

                self.serial_data = []

            else:
                print('Data array did not contain all data points. Data was not inserted into database.')
                print(self.serial_data)
                self.serial_data = []


        except Exception as e:
            print(e)

    except KeyboardInterrupt:
        #Message box that informs user weight collection has stopped.
        print("Data collection stopped. Waiting on python to finish processing queue and close video
window.")

        #Insert STOP into queue will tell STOP data processing at the STOP statement
        self.data_queue.put("STOP")

        c.key = 3
```

```
    def insert_into_table(self):

        # Database connection to database in use. Look above at "self.database_name" to change database
name.
        self.conn_WODB = sqlite3.connect(self.p + '/Documents/00 Thesis work/Walkover scale study/' +
self.database_name + '.db')

        self.cursor = self.conn_WODB.cursor()

        t = time.strftime("%Y%m%d-%H%M%S")
        # print(t)

        self.file_name_time = t.replace('-',  '_')

        self.create_table()

        self.sql = "INSERT INTO " + self.table_name + """
         (Times_s, LC1, LC2, LC3, LC4, LC5, LC6, LC7, LC8, LC9, LC10, LC11, LC12)
         values(?,?,?,?,?,?,?,?,?,?,?,?,?);"""

        # Are we collecting data
        if self.data_collection_statement == False:
            print('  Data being collected and inserting into database "' + self.database_name + '".')
            print("  Press 'Ctrl + C' to end data collection")
            self.data_collection_statement = True

        while True:
            if not self.data_queue.empty():
                data = self.data_queue.get()

                if data is not "STOP":
                    self.conn_WODB.execute(self.sql, data)

                    self.conn_WODB.commit()

                    self.sqlite_table_name.insert(0,self.database_name)

                    self.scale_info.insert(0,data)


                    # print(data)

                else:
                    print("Queue processing finished.")
                    break
```

```
    def create_table(self):

        f = str(self.file_name_time)

        tb = str(self.table_name_for_sqlite.replace(' ','_'))

        #Replaces any white spaces in middle of table name with underscore
        self.table_name = tb + '_' + f
        # self.table_name = tb

        if any([n == self.table_name_for_sqlite for n in self.no_no_characters]):
            print('File name contains invalid characters.')

        else:
            try:
                #Querys Walkover_data.db to see if there is a table with same name as self.table_name from
home page
                query = "SELECT COUNT(*) FROM " + self.table_name + ";"

                self.cursor.execute(query)
                # cursor.commit()
                values = self.cursor.fetchall()
                values = int(values[0][0])

                #If file exists, there will be rows, this just pulls up an error message saying file exists.
                if values > 0:
                    print("I will never get here.")

            except Exception as e:

                # Create tables
                sql_maybe = "CREATE TABLE IF NOT EXISTS " + self.table_name + """
                 (id integer primary key autoincrement, Times_s real,
                 LC1 real, LC2 real, LC3 real,
                 LC4 real, LC5 real, LC6 real,
                 LC7 real, LC8 real, LC9 real,
                 LC10 real, LC11 real, LC12 real);"""

                self.conn_WODB.execute(sql_maybe)
                self.conn_WODB.commit()

                print("Table '" + self.table_name + "' created.")
```

```python
if __name__ == '__main__':

    p = PASS()
    c = Cam()

    c.video_name = p.table_name_for_sqlite

    thread1 = Thread(target = p.insert_into_table, daemon=False)
    thread2 = Thread(target = c.video, daemon = False)

    thread1.start()
    thread2.start()

    p.Arduino_data()
```

APPENDIX E

#Thread 2 (Video Recording of Data Sets)

```
import time
import cv2
import numpy as np
from queue import Queue
import sys
import cv2
from os.path import isdir
from os.path import expanduser

class Camera(object):
  def __init__(self, **kwargs):
    self.video_name = ""

    self.p = expanduser('~')

    self.key = 0

  def video(self, **kwargs):
    #Create variable to open webcam
    vid = cv2.VideoCapture(0)

    x = int(0)
    y = int(475)

    pos = (x,y)

    font = cv2.FONT_HERSHEY_COMPLEX_SMALL

    #fc = (g,b,r). Text font color on image for orange
    fc = (0,165,255)

    #Text thickness on image
    th = 4

    size = -10
    #Create variable to save webcam video during lab testing
    # save = cv2.VideoWriter(self.p + '/Documents/Thesiscode/Thesis data/Lab testing Videos/' +
self.video_name + '.avi', 0, 80.0, (640,480))
    t = time.strftime("%Y%m%d-%H%M%S")

    name = self.video_name + "_" + t.replace('-',  '_')

    video_dir = self.p + '/Documents/00 Thesis work//Walkover scale study/Lab testing Videos/'
```

```
    video_path = video_dir + name + '.avi'

    try:

        dir_exists = isdir(video_dir)

        if dir_exists == True:

            #Create variable to save webcam video during cattle walkover testing
            save = cv2.VideoWriter(video_path, 0, 20.0, (640,480))
            # save = cv2.VideoWriter(self.p + '/Documents/00 Thesis work//Walkover scale
study/Walkover_videos/2 scales/' + name + '.avi', 0, 80.0, (640,480))

            print("Video '" + name + "' created.")

            while self.key is not 3:

                t1 = time.time()
                t_string = str(t1)
                # print(t_string)

                # cv2.createTrackbar('Time', 'Video', 300, 800, )
                ret, frame = vid.read()

                ## Flip the frame.
                ## If the camera is pointed towards the computer user, uncomment out the statement
below.
                ## If the camera is pointed away from the computer user, comment out the statement
below.
                # frame = cv2.flip(frame, 1)

                if ret==True:
                    # cv2.flip(frame, 1)

                    cv2.putText(frame, t_string, pos, font, 4, fc, th, size)

                    # write the flipped frame
                    save.write(frame)

                    cv2.imshow('Video', frame)
                    cv2.waitKey(5)

                    #Ctrl+C = decimal of 3. Therefore, press Ctrl+C key to kill video
                    if cv2.waitKey(5) & 0xFF == 3:
                        break
                else:
                    break
```

```
        vid.release()
        save.release()
        cv2.destroyAllWindows()
        print("Closed video window.")

    else:

        print('VIDEO DIRECTORY DOES NOT EXIST!!!!!!!!!!!!!!!!!!!!!!!!!!!!!')

except Exception as e:
    print(e)
```

APPENDIX F

2 SCALE DATA SETS

Data Sets Used	Date	Static Weight (lbs)	ID from Static Scale	Time of Static Weight Taken	File Name (Data Set Name)	Quality of Data
	16-Jul	676	505	6:59:53		
1	16-Jul	682	505	7:10:53	Tag_180505_20180716_070843	GOOD
2	16-Jul	672	505	7:37:28	Tag_180505_20180716_073519	GOOD
3	16-Jul	580	1500	6:46:44	Tag_181500_20180716_064435	GOOD
4	16-Jul	592	1500	7:23:20	Tag_181500_20180716_072109	GOOD
5	16-Jul	588	1500	7:45:39	Tag_181500_20180716_074328	GOOD
6	16-Jul	510	3000	6:49:52	Tag_183000_20180716_064744	GOOD
7	16-Jul	510	3000	7:30:52	Tag_183000_20180716_072836	GOOD
8	16-Jul	510	3000	7:35:38	Tag_183000_20180716_073324	GOOD
9	16-Jul	546	3501	6:55:18	Tag_183501_20180716_065304	GOOD
10	16-Jul	546	3501	7:27:18	Tag_183501_20180716_072509	GOOD
11	16-Jul	542	3501	7:36:45	Tag_183501_20180716_073436	GOOD
12	16-Jul	506	3504	6:55:36	Tag_183504_20180716_065320	GOOD
13	16-Jul	504	3504	7:30:23	Tag_183504_20180716_072814	GOOD
14	16-Jul	502	3504	7:39:36	Tag_183504_20180716_073723	GOOD
15	16-Jul	490	4444	6:55:01	Tag_184444_20180716_065244	GOOD
16	16-Jul	486	4444	7:21:22	Tag_184444_20180716_071911	GOOD
17	16-Jul	489	4444	7:46:16	Tag_184444_20180716_074402	GOOD
18	16-Jul	532	4448	6:40:13	Tag_184448_20180716_063803	GOOD
19	16-Jul	522	4448	7:23:45	Tag_184448_20180716_072137	GOOD
20	16-Jul	512	4448	7:41:16	Tag_184448_20180716_073903	GOOD
	16-Jul	506	4449	6:56:21		
	16-Jul	489	4449	7:31:16	Tag_184449_20180716_072904	BAD
	16-Jul	485	4449	7:44:15		
	16-Jul				Tag_184451_20180716_065634	GOOD
	16-Jul	474	4451	7:06:34	Tag_184451_20180716_070526	BAD
21	16-Jul	467	4451	7:40:25	Tag_184451_20180716_073809	GOOD
	16-Jul				Tag_184501_20180716_065721	BAD
22	16-Jul	638	5400	7:28:29	Tag_185400_20180716_072628	GOOD
	16-Jul	652	5400	7:46:45		
23	16-Jul	643	5401		Tag_185401_20180716_065348	GOOD
24	16-Jul	642	5401	7:04:51	Tag_185401_20180716_070252	GOOD
25	16-Jul	644	5401	7:43:44	Tag_185401_20180716_074146	GOOD
26	16-Jul	556	5503	7:21:54	Tag_185503_20180716_071947	GOOD
27	16-Jul	550	5503	7:39:03	Tag_185503_20180716_073658	GOOD
	16-Jul	552	5506	6:47:32		
28	16-Jul	560	5506	7:10:12	Tag_185506_20180716_070814	GOOD
	16-Jul	546	5506	7:38:42	Tag_185506_20180716_073633	BAD
	16-Jul	588	5510	6:45:59	Tag_185510_20180716_064354	BAD
29	16-Jul	592	5510	7:12:15	Tag_185510_20180716_071016	GOOD
30	16-Jul	592	5510	7:45:15	Tag_185510_20180716_074303	GOOD
	16-Jul				Tag_185516_20180716_064805	BAD
	16-Jul	582	5516	7:03:41	Tag_185516_20180716_070133	BAD
	16-Jul	574	5516	7:37:52	Tag_185516_20180716_073541	BAD
31	16-Jul	692	5517	6:58:25	Tag_185517_20180716_065606	GOOD
	16-Jul	712	5517	7:22:40	Tag_185517_20180716_072038	BAD
32	16-Jul	684	5517	7:44:41	Tag_185517_20180716_074233	GOOD
	16-Jul	578	5518	6:46:23	Tag_185518_20180716_064412	BAD
33	16-Jul	586	5518	7:24:11	Tag_185518_20180716_072207	GOOD
	16-Jul	588	5518	7:35:18	Tag_185518_20180716_073306	BAD
34	16-Jul	634	5521	6:50:40	Tag_185521_20180716_064828	GOOD
35	16-Jul	638	5521	7:26:25	Tag_185521_20180716_072439	GOOD
36	16-Jul	618	5521	7:40:44	Tag_185521_20180716_073839	GOOD
37	16-Jul	600	6504	6:51:29	Tag_186504_20180716_064919	GOOD
	16-Jul	584	6504	7:29:05	Tag_186504_20180716_072726	BAD
38	16-Jul	594	6504	7:42:55	Tag_186504_20180716_074047	GOOD
	16-Jul				Tag_186505_20180716_065744	GOOD
	16-Jul				Tag_187500_20180716_072329	GOOD
	16-Jul	650	7506	6:42:08		
	16-Jul	652	7506	7:24:46		
	16-Jul	640	7506	7:36:24		
	16-Jul				Tag_187508_20180716_064851	GOOD
39	16-Jul	622	7508	7:05:47	Tag_187508_20180716_070349	GOOD
40	16-Jul	614	7508	7:43:22	Tag_187508_20180716_074109	GOOD
	16-Jul	580	7514	6:40:43	Tag_187514_20180716_063842	BAD
	16-Jul	582	7514	7:32:05	Tag_187514_20180716_073005	BAD
	16-Jul	574	7514	7:38:18	Tag_187514_20180716_073611	BAD
41	16-Jul	612	7516	6:59:14	Tag_187516_20180716_065702	GOOD
42	16-Jul	616	7516	7:27:48	Tag_187516_20180716_072547	GOOD
43	16-Jul	616	7516	7:35:59	Tag_187516_20180716_073344	GOOD
	16-Jul				Tag_189500_20180716_064017	GOOD
	16-Jul				Tag_189500_20180716_073416	GOOD
44	16-Jul	710	9501	7:31:41	Tag_189501_20180716_072928	GOOD
	16-Jul	698	9501	7:42:14		
45	16-Jul	648	9502	6:39:29	Tag_189502_20180716_063736	GOOD
46	16-Jul	644	9502	7:20:16	Tag_189502_20180716_071833	GOOD

APPENDIX G

3 SCALE DATA SETS

Data Sets Used	Date	Static Weight (lbs)	ID from Static Scale	File Name (Data Set Name)	Quality of Data
	22-Jun	632	505	Tag_18505_20180622_095825	BAD
1	22-Jun	562	1500	Tag_181500_20180622_100012	GOOD
2	22-Jun	500	3000	Tag_183000_20180622_095742	GOOD
3	22-Jun	502	3501	Tag_183501_20180622_095554	GOOD
4	22-Jun	477	3504	Tag_183504_20180622_094616	GOOD
5	22-Jun	432	4444	Tag_184444_20180622_095945	GOOD
6	22-Jun	500	4448	Tag_184448_20180622_094532	GOOD
7	22-Jun	442	4449	Tag_184449_20180622_094838	GOOD
8	22-Jun	434	4451	Tag_184451_20180622_095618	GOOD
9	22-Jun	614	5400	Tag_185400_20180622_095520	GOOD
10	22-Jun	616	5401	Tag_185401_20180622_095450	GOOD
11	22-Jun	502	5503	Tag_185503_20180622_095918	GOOD
	22-Jun	506	5506	Tag_185506_20180622_095004	BAD
12	22-Jun	556	5510	Tag_185510_20180622_095643	GOOD
	22-Jun	538	5516	Tag_185516_20180622_094406	BAD
13	22-Jun	642	5517	Tag_185517_20180622_094329	GOOD
	22-Jun	566	5518	Tag_185518_20180622_094925	BAD
	22-Jun	600	5521	Tag_185521_20180622_095903	BAD
14	22-Jun	552	6504	Tag_186504_20180622_094730	GOOD
15	22-Jun	628	7506	Tag_187506_20180622_094809	GOOD
16	22-Jun	580	7508	Tag_187508_20180622_095714	GOOD
	22-Jun	556	7514	Tag_187514_20180622_095128	BAD
	22-Jun	588	7516	Tag_187516_20180622_094904	BAD
17	22-Jun	674	9501	Tag_189501_20180622_094659	GOOD
18	22-Jun	622	9502	Tag_189502_20180622_094216	GOOD
19	27-Jun	656	505	Tag_18505_20180627_075139	GOOD
20	27-Jun	508	3000	Tag_183000_20180627_074733	GOOD
21	27-Jun	538	3501	Tag_183501_20180627_075704	GOOD
	27-Jun	497	3504		
22	27-Jun	466	4444	Tag_184444_20180627_075055	GOOD
23	27-Jun	516	4448	Tag_184448_20180627_075814	GOOD
24	27-Jun	475	4449	Tag_184449_20180627_080155	GOOD
25	27-Jun	468	4451	Tag_184451_20180627_075324	GOOD
26	27-Jun	654	5400	Tag_185400_20180627_075437	GOOD
27	27-Jun	644	5401	Tag_185401_20180627_074536	GOOD
28	27-Jun	518	5503	Tag_185503_20180627_075356	GOOD
29	27-Jun	536	5506	Tag_185506_20180627_074938	GOOD
30	27-Jun	594	5510	Tag_185510_20180627_080044	GOOD
	27-Jun	566	5516	Tag_185516_20180627_074846	BAD
31	27-Jun	696	5517	Tag_185517_20180627_075536	GOOD
32	27-Jun	584	5518	Tag_185518_20180627_075608	GOOD
33	27-Jun	640	5521	Tag_185521_20180627_074817	GOOD
34	27-Jun	652	7506	Tag_187506_20180627_075030	GOOD
35	27-Jun	586	7514	Tag_187514_20180627_074653	GOOD
36	27-Jun	600	7516	Tag_187516_20180627_075944	GOOD
37	27-Jun	688	9501	Tag_189501_20180627_075743	GOOD
38	27-Jun	638	9502	Tag_189502_20180627_080115	GOOD

APPENDIX E

SUCCESSIVE INCREASE/DECREASE IN DATA VALUES 2 SCALE BEEF CATTLE

m_threshold	r^2	mean diff (lbs)	stdev diff (lbs)	max diff (lbs)	min diff (lbs)	lower limit (lbs)	upper limit (lbs)	Sample Size
	Scale 1							
5	0.01	-463.86	141.57	-129.31	-691.98	-741.32	-186	46
6	0.02	-448.34	143.78	-120.44	-691.99	-730.15	-167	46
7	0.02	-413.94	142.86	-115.50	-691.99	-693.94	-134	46
8	0.02	-375.93	131.87	-114.28	-640.62	-634.40	-117	45
9	0.02	-352.60	132.30	-115.51	-639.17	-611.90	-93	45
10	0.00	-329.65	118.16	-118.86	-615.97	-561.24	-98	45
11	0.03	-299.13	99.10	-124.76	-580.89	-493.35	-105	45
12	0.03	-288.37	100.70	-140.20	-579.42	-485.73	-91	45
13	0.07	-279.66	97.40	-132.77	-577.95	-470.55	-89	45
14	0.07	-275.75	97.62	-126.12	-576.48	-467.09	-84	45
15	0.14	-266.92	86.31	-120.20	-541.31	-436.10	-98	45
16	0.11	-253.40	92.60	-115.03	-541.31	-434.88	-72	44
17	0.12	-250.72	93.16	-110.77	-541.42	-433.30	-68	44
18	0.13	-246.51	94.11	-107.41	-541.42	-430.95	-62	44
19	0.16	-240.81	90.54	-115.51	-499.47	-418.27	-63	42
20	0.12	-238.50	92.27	-113.17	-498.73	-419.35	-58	41
21	0.13	-236.02	90.38	-111.66	-468.64	-413.15	-59	41
22	0.11	-238.60	88.56	-126.59	-468.30	-412.16	-65	41
23	0.13	-240.90	87.86	-130.27	-467.98	-413.10	-69	41
24	0.01	-247.30	100.24	-128.80	-503.59	-443.77	-51	40
25	0.04	-248.70	100.29	-127.56	-504.27	-445.27	-52	40
26	0.04	-245.50	95.61	-125.56	-505.03	-432.88	-58	40
27	0.04	-245.15	95.45	-123.95	-505.87	-432.23	-58	40
28	0.03	-250.57	96.62	-122.70	-506.73	-439.93	-61	40
29	0.03	-256.41	99.33	-121.81	-507.62	-451.09	-61.72	40
30	0.01	-277.65	109.37	-121.34	-621.61	-492.01	-63.29	39
	Scale 2							
5	0.00	-472.56	116.65	-281.67	-691.98	-701.20	-244	46
6	0.00	-440.86	118.28	-235.73	-644.51	-672.69	-209	46
7	0.00	-415.81	108.20	-232.30	-644.50	-627.87	-204	46
8	0.01	-390.94	103.86	-228.94	-644.54	-594.50	-187	46
9	0.00	-378.34	99.19	-222.39	-644.54	-572.75	-184	46
10	0.00	-363.16	93.08	-211.13	-644.55	-545.59	-181	46
11	0.01	-348.45	84.48	-164.42	-540.07	-514.02	-183	46
12	0.02	-341.49	86.30	-158.79	-539.26	-510.63	-172	46
13	0.03	-334.17	85.12	-154.77	-538.47	-500.99	-167	46
14	0.03	-329.62	85.53	-152.44	-537.69	-497.26	-162	46
15	0.03	-326.28	86.47	-151.62	-536.93	-495.75	-157	45
16	0.05	-321.70	82.09	-152.10	-536.18	-482.60	-161	45
17	0.07	-319.81	78.76	-187.16	-535.44	-474.18	-165	45
18	0.07	-318.64	78.41	-189.74	-534.70	-472.33	-165	45
19	0.12	-332.77	74.88	-186.36	-533.97	-479.53	-186	44
20	0.12	-331.99	75.20	-183.28	-533.25	-479.37	-185	44
21	0.03	-334.54	83.15	-180.49	-539.37	-497.52	-172	43
22	0.04	-336.87	89.15	-178.01	-539.98	-511.60	-162	42
23	0.04	-332.31	85.69	-175.81	-540.64	-500.26	-164	41
24	0.08	-325.53	76.28	-173.87	-541.35	-475.03	-176	39
25	0.15	-320.76	70.70	-172.24	-501.22	-459.33	-182	38
26	0.15	-324.18	74.57	-170.95	-501.04	-470.34	-178	38
27	0.06	-335.77	91.92	-170.03	-569.42	-515.94	-156	38
28	0.06	-335.83	92.84	-186.32	-571.61	-517.78	-153.87	38
29	0.08	-340.14	96.79	-185.80	-573.87	-529.83	-150.44	36
30	0.22	-333.42	83.00	-185.41	-553.31	-496.10	-170.74	34

m_threshold	r^2	mean diff (lbs)	stdev diff (lbs)	max diff (lbs)	min diff (lbs)	lower limit (lbs)	upper limit (lbs)	Sample Size
	Scale 1 + 2							
5	0.00	-426.20	171.62	-44.11	-691.97	-762.56	-90	46
6	0.00	-395.96	175.62	-35.75	-691.97	-740.16	-52	46
7	0.00	-363.77	175.04	-28.37	-691.97	-706.85	-21	46
8	0.00	-274.90	146.76	-21.97	-644.64	-562.54	13	46
9	0.00	-259.59	141.96	-16.18	-644.68	-537.82	19	46
10	0.00	-249.33	146.22	-10.92	-644.90	-535.90	37	46
11	0.06	-220.05	121.54	-6.43	-583.87	-458.26	18	46
12	0.12	-192.04	101.72	-2.65	-541.31	-391.41	7	46
13	0.08	-181.47	109.15	46.04	-541.30	-395.40	32	46
14	0.07	-170.57	109.33	45.88	-541.29	-384.85	44	46
15	0.10	-156.24	101.35	44.30	-541.29	-354.88	42	45
16	0.11	-151.26	101.59	41.43	-541.38	-350.36	48	45
17	0.12	-142.44	97.51	39.04	-480.46	-333.55	49	45
18	0.17	-129.40	85.17	32.18	-397.26	-296.32	38	45
19	0.26	-124.21	80.08	25.46	-395.75	-281.17	33	45
20	0.30	-123.68	81.24	-2.56	-394.31	-282.91	36	45
21	0.35	-117.66	79.54	-1.49	-392.93	-273.54	38	44
22	0.38	-107.44	65.41	-0.70	-369.78	-235.63	21	43
23	0.39	-105.37	65.14	-0.17	-369.60	-233.04	22	43
24	0.29	-102.29	71.52	0.08	-372.42	-242.48	38	43
25	0.29	-101.76	72.08	0.09	-372.55	-243.04	40	43
26	0.17	-107.94	92.68	-0.08	-447.97	-289.59	74	43
27	0.15	-105.44	94.50	1.15	-448.52	-290.67	80	43
28	0.19	-112.36	101.62	59.99	-449.14	-311.54	87	42
29	0.17	-120.88	116.50	62.14	-449.87	-349.22	107.46	42
30	0.16	-121.04	117.21	64.05	-450.65	-350.77	108.69	42

APPENDIX F

AVERAGE EVERYTHING BETWEEN REGRESSION 2 SCALE BEEF CATTLE

Wt_Threshold (lbs)	r^2	mean diff (lbs)	stdev diff (lbs)	max diff (lbs)	min diff (lbs)	lower limit (lbs)	upper limit (lbs)	Sample Size
	Scale 1							
1	0.17	-343.52	65.17	-233.03	-481.75	-471.26	-216	45
5	0.21	-331.74	61.88	-226.26	-467.93	-453.02	-210	45
10	0.21	-326.84	61.71	-222.10	-459.23	-447.78	-206	45
20	0.22	-319.83	61.31	-216.53	-446.97	-439.99	-200	45
30	0.22	-314.94	61.28	-212.34	-440.69	-435.04	-195	45
40	0.22	-311.13	61.44	-209.59	-437.58	-431.54	-191	45
50	0.22	-307.28	61.66	-206.89	-434.43	-428.13	-186	45
60	0.22	-302.98	62.03	-204.23	-428.15	-424.57	-181	45
70	0.22	-298.75	62.68	-201.63	-425.05	-421.60	-176	45
80	0.22	-295.36	62.67	-199.12	-421.94	-418.19	-173	45
90	0.22	-292.81	62.77	-196.64	-415.93	-415.85	-170	45
100	0.23	-289.57	63.48	-194.20	-415.93	-413.99	-165	45
150	0.23	-276.84	64.29	-182.40	-399.40	-402.84	-151	45
200	0.21	-265.70	67.40	-141.12	-390.19	-397.81	-134	45
250	0.17	-254.72	71.68	-126.10	-380.84	-395.21	-114	45
300	0.13	-229.22	72.28	-116.91	-389.12	-370.88	-88	42
350	0.03	-176.22	84.29	-33.34	-372.77	-341.43	-11	32
400	0.02	-110.72	80.77	23.31	-308.00	-269.02	48	25
450	0.21	-57.30	66.12	52.96	-217.55	-186.90	72	22
500	0.60	-15.60	40.67	76.59	-75.21	-95.31	64	22
550	0.51	0.90	36.63	92.51	-55.25	-70.89	73	17
600	0.50	19.64	33.80	110.09	-17.86	-46.61	86	13
650	0.55	32.18	28.35	89.36	-0.38	-23.39	88	7
700	1.00	79.93	56.65	119.99	39.87	-31.10	191	2
	Scale 2							
1	0.15	-405.28	61.13	-284.99	-544.79	-525.10	-285	46
5	0.12	-390.68	63.30	-273.85	-534.50	-514.73	-267	46
10	0.13	-383.84	63.17	-256.44	-530.45	-507.66	-260	46
20	0.15	-372.75	63.89	-251.35	-524.98	-497.96	-248	46
30	0.16	-364.13	63.80	-249.21	-522.28	-489.19	-239	46
40	0.16	-356.88	63.82	-211.56	-519.68	-481.96	-232	46
50	0.17	-351.75	62.50	-208.67	-518.43	-474.24	-229	46
60	0.18	-347.66	62.09	-202.94	-516.04	-469.36	-226	46
70	0.19	-344.68	61.47	-200.12	-513.82	-465.17	-224	46
80	0.19	-341.99	61.20	-197.39	-513.82	-461.94	-222	46
90	0.19	-339.50	61.17	-194.70	-511.83	-459.40	-220	46
100	0.20	-337.20	60.83	-194.70	-510.95	-456.43	-218	46
150	0.19	-324.10	60.87	-185.05	-506.19	-443.41	-205	46
200	0.16	-313.29	62.57	-177.62	-493.32	-435.91	-191	46
250	0.23	-284.18	57.06	-171.48	-404.35	-396.02	-172	43
300	0.09	-249.11	66.56	-90.98	-378.35	-379.57	-119	35
350	0.06	-181.83	72.38	-64.12	-368.41	-323.70	-40	22
400	0.05	-140.87	74.76	-4.66	-322.82	-287.40	6	19
450	0.00	-126.79	70.56	11.44	-296.59	-265.09	12	16
500	0.24	-87.00	54.65	28.20	-192.29	-194.12	20	12
550	0.97	-66.61	5.01	-62.67	-72.25	-76.43	-57	3
600	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1
650	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1
700	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0

Wt_Threshold (lbs)	r^2	mean diff (lbs)	stdev diff (lbs)	max diff (lbs)	min diff (lbs)	lower limit (lbs)	upper limit (lbs)	Sample Size
	Scale 1 + 2							
1	0.40	-249.12	51.88	-150.89	-401.62	-350.80	-147	46
5	0.40	-233.84	51.27	-133.30	-392.93	-334.34	-133	46
10	0.42	-225.64	50.89	-117.10	-379.95	-325.38	-126	46
20	0.47	-208.92	49.75	-112.21	-369.06	-306.44	-111	46
30	0.47	-196.72	49.62	-108.54	-357.30	-293.98	-99	46
40	0.45	-186.44	51.04	-83.29	-353.20	-286.48	-86	46
50	0.46	-178.76	50.97	-75.99	-344.98	-278.67	-79	46
60	0.46	-172.37	51.78	-72.31	-340.88	-273.84	-71	46
70	0.46	-168.23	52.13	-64.95	-340.88	-270.41	-66	46
80	0.46	-164.20	52.10	-61.25	-333.10	-266.30	-62	46
90	0.46	-160.84	52.35	-53.92	-333.10	-263.45	-58	46
100	0.45	-157.20	52.72	-53.92	-333.10	-260.53	-54	46
150	0.46	-138.31	53.26	-32.39	-319.99	-242.70	-34	46
200	0.44	-122.35	54.28	-15.46	-313.56	-228.74	-16	46
250	0.44	-103.46	56.29	-2.82	-311.44	-213.79	7	46
300	0.46	-72.31	51.41	30.11	-216.33	-173.08	28	46
350	0.50	-44.72	51.30	38.68	-193.82	-145.27	56	46
400	0.40	-15.83	57.27	113.37	-181.24	-128.08	96	45
450	0.37	9.75	57.45	137.73	-170.33	-102.85	122	45
500	0.36	32.44	60.68	149.51	-161.72	-86.49	151	45
550	0.32	58.18	61.44	166.46	-110.91	-62.24	179	41
600	0.18	106.28	69.59	282.04	-48.20	-30.12	243	37
650	0.21	137.89	65.61	301.04	-45.11	9.30	266	36
700	0.10	165.26	70.72	318.63	-45.54	26.65	304	33

APPENDIX G

FFT TABLES 2 – SCALE BEEF CATTLE

	Source	r2	mean diff	stdev diff	upper limit	lower limit	sample size
DC	Scale 1 + 2	0.03	-352.03	77.41	-200.31	-503.75	46
	Scale 1	0.01	-458.30	73.42	-314.40	-602.20	46
	Scale 2	0.03	-477.06	67.26	-345.24	-608.88	46
DC + 1	Scale 1 + 2	0.41	-273.64	51.77	-172.18	-375.10	46
	Scale 1	0.11	-491.41	60.56	-372.71	-610.11	46
	Scale 2	0.11	-507.63	60.38	-389.29	-625.97	46
Max Ampliturde	Scale 1 + 2	0.35	-269.66	54.24	-163.36	-375.96	46
	Scale 1	0.01	-458.30	73.42	-314.41	-602.20	46
	Scale 2	0.03	-477.06	67.26	-345.24	-608.88	46

APPENDIX H

RMS 2 – SCALE BEEF CATTLE

Wt_Threshold (lbs)	r^2	mean diff (lbs)	stdev diff (lbs)	max diff (lbs)	min diff (lbs)	lower limit (lbs)	upper limit (lbs)	Sample Size
Scale 1								
1	0.20	-305.85	67.59	-199.49	-440.75	-438.32	-173	45
5	0.21	-298.97	65.71	-195.62	-435.93	-427.76	-170	45
10	0.22	-296.10	65.66	-193.23	-430.84	-424.79	-167	45
Scale 2								
1	0.17	-367.57	62.09	-232.29	-527.47	-489.26	-246	46
5	0.15	-358.57	63.89	-225.23	-521.74	-483.80	-233	46
10	0.16	-354.38	64.02	-221.48	-519.44	-479.85	-229	46
Scale 1 + 2								
1	0.47	-175.86	53.00	-87.10	-363.17	-279.74	-72	46
5	0.46	-166.42	52.99	-77.80	-357.54	-270.27	-63	46
10	0.47	-161.41	52.95	-71.22	-349.18	-265.18	-58	46

APPENDIX I

SUCCESSIVE INCREASE/DECREASE IN DATA VALUES 3 SCALE BEEF CATTLE

m_threshold	r²	mean diff (lbs)	stdev diff (lbs)	max diff (lbs)	min diff (lbs)	lower limit (lbs)	upper limit (lbs)	Sample Size
	Scale 1							
5	0.02	-396.60	113.70	-211.24	-696.28	-619.45	-174	35
6	0.01	-385.31	116.36	-202.23	-696.28	-613.38	-157	35
7	0.01	-372.00	115.40	-194.48	-696.30	-598.19	-146	35
8	0.00	-340.13	107.58	-151.63	-654.13	-550.98	-129	36
9	0.03	-316.54	89.42	-148.09	-635.41	-491.79	-141	37
10	0.07	-304.96	85.72	-144.95	-632.49	-472.96	-137	37
11	0.10	-295.06	85.90	-142.21	-629.60	-463.43	-127	37
12	0.20	-286.35	76.49	-139.87	-555.60	-436.27	-136	37
13	0.17	-281.05	81.38	-57.51	-553.56	-440.56	-122	37
14	0.20	-277.33	80.21	-62.22	-551.63	-434.54	-120	37
15	0.22	-275.97	79.04	-68.62	-549.80	-430.89	-121	37
16	0.27	-275.46	76.27	-76.67	-527.47	-424.95	-126	36
17	0.29	-274.51	75.26	-86.22	-526.75	-422.01	-127	36
18	0.32	-276.61	73.86	-96.97	-526.05	-421.38	-132	36
19	0.32	-277.24	74.35	-108.70	-525.39	-422.97	-132	36
20	0.47	-273.47	62.72	-121.30	-421.52	-396.40	-151	36
21	0.41	-280.42	69.28	-134.64	-431.06	-416.21	-145	35
22	0.41	-285.85	68.21	-177.79	-431.34	-419.54	-152	32
23	0.33	-289.15	73.84	-177.36	-431.63	-433.88	-144	30
24	0.33	-292.92	72.78	-177.63	-431.95	-435.56	-150	30
25	0.31	-296.08	75.50	-178.65	-432.29	-444.05	-148	30
26	0.33	-300.24	72.25	-177.06	-432.63	-441.84	-159	29
27	0.25	-312.80	83.53	-175.19	-505.60	-476.52	-149	26
28	0.31	-323.35	76.58	-173.46	-476.01	-473.45	-173	25
29	0.14	-344.03	97.22	-171.88	-564.07	-534.58	-153.49	24
30	0.27	-352.74	91.56	-210.16	-565.21	-532.20	-173.28	23
	Scale 2							
5	0.00	-388.28	100.90	-202.01	-604.62	-586.04	-191	38
6	0.01	-368.25	98.51	-189.58	-602.26	-561.33	-175	38
7	0.17	-339.80	79.02	-177.79	-510.32	-494.67	-185	38
8	0.10	-324.33	87.00	-79.72	-507.22	-494.85	-154	38
9	0.11	-314.68	88.42	-65.64	-504.33	-487.99	-141	38
10	0.06	-299.21	94.81	-53.96	-501.68	-485.03	-113	38
11	0.06	-292.69	95.52	-45.42	-499.29	-479.90	-105	38
12	0.09	-278.80	91.95	-40.26	-497.19	-459.02	-99	38
13	0.14	-275.08	89.39	-38.44	-468.29	-450.28	-100	38
14	0.15	-269.78	89.73	-39.98	-464.06	-445.64	-94	38
15	0.19	-258.11	83.94	-44.74	-450.97	-422.64	-94	38
16	0.21	-257.56	82.85	-52.20	-449.84	-419.94	-95	38
17	0.23	-252.35	78.44	-61.86	-448.76	-406.08	-99	38
18	0.24	-251.03	77.81	-73.40	-447.75	-403.54	-99	38
19	0.25	-248.84	78.55	-86.64	-446.80	-402.80	-95	38
20	0.31	-248.09	79.73	-113.44	-445.91	-404.36	-92	37
21	0.33	-253.32	83.70	-115.30	-445.10	-417.36	-89	37
22	0.27	-246.78	87.20	-16.50	-444.38	-417.69	-76	34
23	0.28	-242.22	80.88	-26.54	-443.75	-400.75	-84	33
24	0.20	-250.66	93.09	-37.77	-488.16	-433.11	-68	30
25	0.15	-264.42	99.04	-49.76	-488.91	-458.55	-70	28
26	0.21	-274.25	93.00	-131.43	-489.68	-456.52	-92	28
27	0.20	-279.34	95.18	-136.15	-490.48	-465.90	-93	26
28	0.17	-279.98	98.04	-141.42	-491.30	-472.13	-87.82	24
29	0.14	-307.44	111.21	-147.26	-544.40	-525.40	-89.47	23
30	0.14	-325.73	115.29	-153.68	-550.78	-551.69	-99.76	23

m_threshold	r^2	mean diff (lbs)	stdev diff (lbs)	max diff (lbs)	min diff (lbs)	lower limit (lbs)	upper limit (lbs)	Sample Size
Scale 3								
5	0.06	-379.56	102.37	-230.91	-653.99	-580.20	-179	36
6	0.10	-350.87	89.93	-219.72	-640.00	-527.13	-175	36
7	0.20	-332.01	75.61	-208.95	-516.76	-480.21	-184	37
8	0.27	-311.81	68.56	-196.12	-516.14	-446.19	-177	36
9	0.26	-298.49	70.77	-189.02	-515.54	-437.21	-160	36
10	0.26	-289.93	70.97	-180.03	-514.94	-429.02	-151	36
11	0.40	-276.05	60.37	-171.85	-417.31	-394.37	-158	36
12	0.30	-267.92	65.70	-104.02	-413.32	-396.69	-139	36
13	0.30	-261.71	65.92	-97.81	-409.44	-390.91	-133	36
14	0.32	-258.55	64.89	-92.29	-405.68	-385.74	-131	36
15	0.39	-253.01	61.43	-87.64	-402.04	-373.41	-133	36
16	0.41	-249.29	61.11	-83.91	-398.53	-369.05	-130	36
17	0.40	-251.95	61.95	-81.06	-395.16	-373.37	-131	35
18	0.42	-251.94	60.52	-79.06	-391.93	-370.55	-133	35
19	0.41	-255.27	65.00	-77.85	-388.83	-382.66	-128	35
20	0.54	-263.56	57.55	-164.62	-385.83	-376.36	-151	35
21	0.52	-264.83	60.01	-163.79	-382.91	-382.46	-147	34
22	0.56	-274.30	61.11	-163.20	-384.06	-394.07	-155	34
23	0.62	-278.01	56.03	-162.84	-385.51	-387.82	-168	34
24	0.68	-289.18	55.65	-168.97	-387.03	-398.25	-180	34
25	0.61	-297.73	66.51	-163.30	-491.79	-428.08	-167	34
26	0.65	-289.99	56.60	-162.08	-383.37	-400.93	-179	32
27	0.62	-293.62	58.76	-161.00	-383.63	-408.79	-178	31
28	0.60	-298.18	59.22	-160.02	-383.92	-414.25	-182	31
29	0.64	-305.35	55.74	-159.08	-384.22	-414.60	-196.11	30
30	0.56	-311.80	64.43	-158.22	-484.53	-438.07	-185.52	29
Scale 1 + 2								
5	0.00	-327.95	137.22	-153.82	-654.09	-596.89	-59	37
6	0.00	-300.36	140.31	-139.15	-654.09	-575.37	-25	37
7	0.00	-248.60	134.42	-52.78	-654.11	-512.06	15	37
8	0.01	-216.93	129.42	-39.70	-654.11	-470.59	37	37
9	0.03	-197.92	137.38	-27.36	-654.11	-467.18	71	37
10	0.00	-171.35	116.03	-8.36	-468.69	-398.78	56	38
11	0.06	-142.80	97.00	-3.08	-463.72	-332.92	47	38
12	0.07	-123.63	94.06	3.31	-458.92	-307.99	61	38
13	0.06	-107.83	106.23	174.87	-454.32	-316.03	100	38
14	0.06	-102.29	105.52	177.29	-449.91	-309.12	105	38
15	0.25	-91.83	93.84	177.97	-331.55	-275.74	92	38
16	0.27	-76.03	88.18	177.04	-334.80	-248.85	97	38
17	0.32	-73.60	80.27	86.59	-338.34	-230.92	84	38
18	0.38	-71.40	76.90	81.62	-342.27	-222.13	79	38
19	0.47	-61.14	62.83	75.98	-219.29	-184.29	62	36
20	0.50	-58.96	61.69	70.82	-214.76	-179.87	62	36
21	0.55	-59.56	57.38	72.19	-210.63	-172.01	53	36
22	0.56	-57.70	55.84	85.23	-206.94	-167.15	52	36
23	0.61	-60.67	51.42	47.89	-203.71	-161.45	40	36
24	0.66	-64.81	48.55	29.03	-200.85	-159.96	30	35
25	0.67	-62.04	47.09	31.20	-198.30	-154.34	30	34
26	0.68	-62.59	48.18	33.03	-195.51	-157.01	32	33
27	0.46	-81.91	91.46	33.96	-448.63	-261.16	97	32
28	0.40	-77.33	80.60	36.45	-448.94	-235.30	81	31
29	0.35	-84.88	101.23	38.81	-449.27	-283.30	113.53	28
30	0.24	-96.53	117.57	41.02	-449.63	-326.97	133.91	27

m_threshold	r²	mean diff (lbs)	stdev diff (lbs)	max diff (lbs)	min diff (lbs)	lower limit (lbs)	upper limit (lbs)	Sample Size
Scale 2 + 3								
5	0.01	-368.00	140.04	-122.23	-695.98	-642.47	-94	38
6	0.00	-336.73	123.70	-108.71	-609.79	-579.19	-94	38
7	0.01	-315.51	124.31	-95.67	-606.76	-559.15	-72	38
8	0.00	-297.41	126.78	-79.64	-603.76	-545.89	-49	38
9	0.01	-276.54	120.82	-65.54	-502.49	-513.35	-40	38
10	0.00	-256.54	125.10	-53.85	-499.93	-501.74	-11	38
11	0.00	-237.96	125.74	-45.30	-497.64	-484.40	8	38
12	0.01	-218.75	121.51	-39.36	-495.64	-456.91	19	38
13	0.06	-206.65	116.42	-33.30	-468.31	-434.82	22	38
14	0.05	-198.03	117.36	-27.98	-464.08	-428.06	32	38
15	0.10	-175.94	103.49	-2.97	-408.63	-378.77	27	38
16	0.13	-166.37	103.83	0.78	-406.16	-369.87	37	38
17	0.18	-156.43	91.63	4.00	-402.45	-336.02	23	38
18	0.20	-150.93	92.06	6.63	-404.60	-331.37	30	38
19	0.22	-153.51	97.82	8.56	-407.09	-345.24	38	38
20	0.36	-143.30	91.16	9.83	-409.90	-321.98	35	36
21	0.35	-143.10	91.68	10.50	-412.88	-322.79	37	36
22	0.39	-146.35	88.62	10.65	-415.98	-320.04	27	36
23	0.51	-150.30	78.78	10.27	-316.99	-304.70	4	35
24	0.47	-153.78	80.54	8.51	-318.30	-311.64	4	35
25	0.52	-163.18	80.41	6.59	-319.64	-320.78	-6	34
26	0.58	-171.07	84.73	4.50	-321.05	-337.14	-5	33
27	0.54	-179.84	78.79	-23.08	-318.82	-334.26	-25	30
28	0.51	-182.46	80.49	-24.79	-320.24	-340.22	-25	30
29	0.45	-193.88	89.02	-26.86	-416.03	-368.37	-19.40	30
30	0.30	-192.32	94.74	-29.28	-417.79	-378.00	-6.64	28
Scale 1 + 3								
5	0.04	-384.44	109.42	-126.99	-696.29	-598.91	-170	35
6	0.07	-360.84	99.86	-117.44	-696.29	-556.57	-165	36
7	0.03	-339.66	106.36	-108.39	-696.29	-548.12	-131	36
8	0.00	-313.28	97.82	-100.00	-638.43	-505.00	-122	37
9	0.00	-306.48	98.54	-92.32	-635.44	-499.62	-113	37
10	0.02	-294.90	95.25	-85.35	-632.52	-481.58	-108	37
11	0.04	-276.14	97.73	-79.22	-629.63	-467.69	-85	37
12	0.06	-265.49	93.61	-74.02	-555.63	-448.96	-82	37
13	0.07	-260.20	93.49	-69.61	-553.59	-443.44	-77	37
14	0.17	-246.17	82.32	-62.59	-403.62	-407.52	-85	36
15	0.14	-240.62	84.43	-62.64	-401.24	-406.09	-75	36
16	0.16	-236.81	82.56	-60.16	-399.44	-398.62	-75	36
17	0.17	-235.14	81.90	-58.27	-398.24	-395.67	-75	36
18	0.17	-231.74	81.96	-56.76	-397.68	-392.37	-71	36
19	0.21	-233.87	82.29	-55.59	-375.49	-395.15	-73	36
20	0.34	-242.69	72.81	-54.84	-375.55	-385.39	-100	35
21	0.42	-251.06	71.29	-54.51	-375.65	-390.79	-111	34
22	0.40	-252.36	70.17	-54.59	-375.81	-389.89	-115	32
23	0.32	-253.01	72.30	-55.02	-376.02	-394.71	-111	31
24	0.32	-257.36	72.94	-55.91	-376.27	-400.33	-114	31
25	0.53	-268.24	59.74	-172.99	-376.56	-385.33	-151	29
26	0.54	-266.45	59.48	-171.22	-376.90	-383.03	-150	28
27	0.54	-268.37	57.23	-169.60	-363.18	-380.54	-156	26
28	0.56	-270.89	55.37	-168.10	-364.22	-379.41	-162	26
29	0.57	-271.94	56.98	-166.75	-365.31	-383.62	-160.26	25
30	0.62	-285.03	58.45	-179.15	-436.25	-399.59	-170.47	25

m_threshold	r²	mean diff (lbs)	stdev diff (lbs)	max diff (lbs)	min diff (lbs)	lower limit (lbs)	upper limit (lbs)	Sample Size
Scale 1 + 2 + 3								
5	0.06	-302.14	160.96	11.03	-696.28	-617.61	13	36
6	0.13	-273.58	165.28	24.14	-696.27	-597.52	50	36
7	0.07	-221.04	162.04	49.99	-654.07	-538.63	97	37
8	0.05	-185.66	153.02	63.98	-578.69	-485.57	114	38
9	0.06	-160.77	145.07	77.06	-473.87	-445.10	124	38
10	0.05	-146.09	145.61	88.74	-468.72	-431.49	139	38
11	0.00	-116.79	126.97	98.80	-463.74	-365.66	132	38
12	0.00	-101.18	124.63	107.35	-458.95	-345.46	143	38
13	0.00	-85.52	124.41	119.29	-454.35	-329.36	158	38
14	0.00	-72.48	131.83	176.94	-449.93	-330.86	186	38
15	0.02	-72.19	134.44	177.61	-445.69	-335.68	191	38
16	0.05	-46.39	117.14	176.68	-331.60	-275.97	183	38
17	0.05	-42.04	112.91	151.36	-334.84	-263.33	179	38
18	0.08	-36.60	110.71	155.53	-338.39	-253.59	180	38
19	0.18	-31.54	111.83	158.21	-342.32	-250.71	188	38
20	0.18	-19.20	100.20	159.44	-305.31	-215.59	177	36
21	0.19	-22.50	93.81	132.89	-305.08	-206.36	161	36
22	0.22	-22.39	90.50	133.23	-304.87	-199.77	155	36
23	0.34	-39.14	89.22	132.73	-304.73	-214.00	136	36
24	0.48	-52.85	89.86	57.69	-304.65	-228.98	123	36
25	0.53	-61.55	93.89	59.16	-304.60	-245.58	122	36
26	0.57	-58.55	87.35	53.64	-304.62	-229.75	113	35
27	0.52	-65.49	88.37	54.18	-304.72	-238.69	108	34
28	0.55	-73.44	81.11	35.22	-304.90	-232.42	86	32
29	0.57	-83.29	84.28	34.51	-305.14	-248.48	81.90	28
30	0.48	-95.17	95.47	33.33	-327.02	-282.30	91.96	28

APPENDIX J

AVERAGE EVERYTHING BETWEEN REGRESSION 3 SCALE BEEF CATTLE

Wt_Threshold (lbs)	r^2	mean diff (lbs)	stdev diff (lbs)	max diff (lbs)	min diff (lbs)	lower limit (lbs)	upper limit (lbs)	Sample Size
				Scale 1				
1	0.35	-358.62	62.80	-253.33	-500.51	-481.71	-236	37
5	0.42	-348.75	58.70	-246.18	-467.84	-463.79	-234	37
10	0.41	-344.68	59.29	-240.89	-464.94	-460.88	-228	37
20	0.39	-338.89	60.27	-234.44	-460.59	-457.02	-221	37
30	0.38	-333.96	60.94	-229.02	-457.72	-453.39	-215	37
40	0.38	-330.13	61.00	-224.66	-454.98	-449.69	-211	37
50	0.37	-326.14	61.54	-220.34	-454.98	-446.76	-206	37
60	0.38	-322.52	61.45	-214.95	-454.98	-442.96	-202	37
70	0.38	-318.49	61.55	-204.98	-454.98	-439.12	-198	37
80	0.37	-315.15	61.92	-201.61	-454.98	-436.51	-194	37
90	0.45	-308.99	57.20	-198.30	-440.68	-421.10	-197	37
100	0.44	-306.02	57.53	-196.18	-439.52	-418.79	-193	37
150	0.45	-292.52	57.43	-187.55	-429.25	-405.09	-180	37
200	0.41	-281.83	60.12	-167.30	-422.44	-399.66	-164	37
250	0.28	-263.73	67.29	-147.00	-416.90	-395.62	-132	37
300	0.12	-246.16	66.12	-111.41	-360.00	-375.75	-117	28
350	0.08	-199.76	75.65	-46.22	-308.78	-348.03	-51	18
400	0.04	-155.61	69.37	-20.10	-300.87	-291.58	-20	14
450	0.14	-109.90	65.90	1.47	-239.45	-239.05	19	12
500	0.41	-54.76	34.63	-19.41	-117.65	-122.64	13	7
550	0.00	-39.30	36.93	-1.52	-98.46	-111.67	33	6
600	0.17	-8.08	24.37	17.06	-48.57	-55.84	40	5
650	0.27	3.45	22.07	17.59	-29.48	-39.81	47	4
700	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
				Scale 2				
1	0.30	-355.63	64.28	-236.92	-491.63	-481.62	-230	38
5	0.23	-340.74	68.13	-219.47	-489.83	-474.27	-207	38
10	0.19	-333.36	70.81	-199.84	-488.05	-472.16	-195	38
20	0.17	-326.06	72.09	-189.12	-485.74	-467.36	-185	38
30	0.17	-317.43	73.08	-152.83	-484.10	-460.67	-174	38
40	0.18	-310.20	72.20	-131.97	-482.56	-451.71	-169	38
50	0.18	-305.36	72.41	-124.67	-481.13	-447.27	-163	38
60	0.18	-300.32	72.54	-117.24	-479.83	-442.49	-158	38
70	0.18	-296.37	72.80	-109.66	-477.40	-439.06	-154	38
80	0.20	-291.68	71.13	-109.66	-462.65	-431.10	-152	38
90	0.19	-287.98	72.11	-94.29	-459.17	-429.31	-147	38
100	0.20	-284.70	71.84	-94.29	-457.30	-425.50	-144	38
150	0.20	-268.94	72.68	-78.93	-431.39	-411.39	-126	38
200	0.12	-250.39	80.13	-64.17	-400.99	-407.45	-93	38
250	0.10	-222.81	79.68	-43.87	-378.99	-378.97	-67	36
300	0.01	-187.83	96.11	2.96	-376.70	-376.20	1	33
350	0.00	-143.92	96.08	22.07	-390.58	-332.23	44	30
400	0.10	-101.30	72.92	38.25	-227.15	-244.22	42	26
450	0.02	-80.64	77.52	56.09	-207.30	-232.58	71	23
500	0.03	-56.82	79.11	70.85	-190.99	-211.88	98	19
550	0.04	-13.19	71.45	81.87	-117.04	-153.22	127	10
600	0.23	37.54	70.02	102.19	-36.84	-99.70	175	3
650	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1
700	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1

Wt_Threshold (lbs)	r^2	mean diff (lbs)	stdev diff (lbs)	max diff (lbs)	min diff (lbs)	lower limit (lbs)	upper limit (lbs)	Sample Size
	Scale 3							
1	0.41	-349.61	60.62	-233.58	-501.91	-468.43	-231	37
5	0.47	-337.18	56.47	-221.84	-457.44	-447.86	-227	36
10	0.47	-331.63	56.45	-209.08	-455.05	-442.28	-221	36
20	0.49	-323.45	55.19	-201.36	-450.25	-431.61	-215	36
30	0.51	-317.37	54.20	-195.49	-446.67	-423.61	-211	36
40	0.53	-311.66	53.21	-191.61	-443.16	-415.95	-207	36
50	0.54	-308.09	52.93	-187.77	-439.74	-411.83	-204	36
60	0.53	-305.07	52.95	-184.00	-437.50	-408.85	-201	36
70	0.53	-302.17	53.17	-182.16	-434.20	-406.38	-198	36
80	0.53	-299.47	53.23	-180.31	-430.98	-403.81	-195	36
90	0.53	-297.76	53.24	-176.70	-429.93	-402.11	-193	36
100	0.52	-295.05	53.79	-173.20	-427.88	-400.47	-190	36
150	0.48	-284.28	56.11	-141.36	-420.70	-394.26	-174	36
200	0.43	-271.47	58.51	-118.67	-415.75	-386.14	-157	36
250	0.33	-249.98	64.01	-107.09	-411.77	-375.45	-125	36
300	0.13	-228.49	69.67	-63.12	-408.42	-365.04	-92	32
350	0.01	-195.98	73.89	-54.47	-344.18	-340.81	-51	23
400	0.01	-151.43	80.11	27.32	-297.75	-308.45	6	21
450	0.09	-106.11	63.31	48.16	-206.39	-230.19	18	17
500	0.08	-78.51	58.19	66.35	-150.60	-192.55	36	12
550	0.29	-52.95	60.38	87.07	-128.45	-171.29	65	10
600	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1
650	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
700	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
	Scale 1 + 2							
1	0.63	-234.30	47.09	-153.30	-340.74	-326.59	-142	38
5	0.57	-212.43	50.69	-122.96	-340.74	-311.79	-113	38
10	0.54	-204.94	52.45	-114.51	-340.74	-307.74	-102	38
20	0.50	-195.73	54.26	-101.21	-340.74	-302.09	-89	38
30	0.50	-184.63	54.38	-90.66	-340.74	-291.21	-78	38
40	0.50	-174.89	54.17	-80.26	-340.74	-281.06	-69	38
50	0.49	-169.09	54.86	-69.45	-340.74	-276.62	-62	38
60	0.48	-162.96	55.42	-61.07	-340.74	-271.59	-54	38
70	0.47	-157.54	55.98	-52.52	-340.74	-267.25	-48	38
80	0.50	-151.39	54.61	-43.81	-340.74	-258.43	-44	38
90	0.66	-141.55	45.67	-37.95	-267.84	-231.07	-52	38
100	0.65	-137.20	46.26	-32.03	-263.25	-227.87	-47	38
150	0.59	-116.86	49.53	-8.43	-248.73	-213.93	-20	38
200	0.58	-98.31	50.01	5.82	-200.02	-196.34	0	38
250	0.50	-73.86	54.23	28.19	-187.01	-180.16	32	38
300	0.52	-50.88	53.14	61.63	-175.87	-155.04	53	38
350	0.49	-20.13	56.51	85.53	-169.13	-130.88	91	38
400	0.41	4.39	65.14	199.77	-161.94	-123.28	132	38
450	0.35	23.07	68.95	237.79	-159.84	-112.06	158	37
500	0.26	52.86	77.32	262.95	-160.90	-98.69	204	36
550	0.38	91.25	61.68	262.95	-3.53	-29.63	212	32
600	0.25	124.50	71.01	299.39	-4.20	-14.67	264	32
650	0.34	161.71	63.10	311.48	75.68	38.03	285	28
700	0.18	181.74	68.40	333.50	75.43	47.67	316	25

Wt_Threshold (lbs)	r^2	mean diff (lbs)	stdev diff (lbs)	max diff (lbs)	min diff (lbs)	lower limit (lbs)	upper limit (lbs)	Sample Size
	Scale 2 + 3							
1	0.61	-253.46	47.94	-149.57	-355.04	-347.41	-160	38
5	0.59	-242.42	49.41	-144.37	-351.51	-339.27	-146	38
10	0.58	-236.22	49.74	-144.37	-347.96	-333.71	-139	38
20	0.59	-227.90	49.45	-133.81	-340.78	-324.83	-131	38
30	0.60	-220.12	48.77	-128.44	-328.54	-315.70	-125	38
40	0.60	-214.70	48.87	-123.09	-326.65	-310.48	-119	38
50	0.60	-210.48	48.63	-123.09	-322.92	-305.79	-115	38
60	0.59	-206.58	49.12	-117.12	-320.20	-302.86	-110	38
70	0.59	-203.11	49.49	-109.53	-316.61	-300.10	-106	38
80	0.59	-200.01	49.48	-109.53	-308.43	-296.99	-103	38
90	0.59	-197.05	49.59	-94.16	-304.77	-294.25	-100	38
100	0.59	-194.16	49.60	-94.16	-302.96	-291.38	-97	38
150	0.54	-181.01	51.97	-78.80	-285.20	-282.87	-79	38
200	0.52	-159.25	54.00	-53.11	-270.21	-265.08	-53	38
250	0.54	-130.94	53.28	-26.07	-222.06	-235.36	-27	38
300	0.41	-107.39	58.81	25.02	-215.91	-222.65	8	38
350	0.32	-85.64	63.55	43.61	-210.70	-210.20	39	38
400	0.41	-56.82	59.62	71.83	-205.38	-173.67	60	38
450	0.43	-29.79	59.88	96.97	-179.50	-147.15	88	37
500	0.40	-13.44	61.95	113.85	-179.51	-134.85	108	36
550	0.10	12.18	68.89	136.07	-185.80	-122.85	147	30
600	0.04	28.92	57.87	138.37	-50.51	-84.51	142	24
650	0.00	52.04	60.00	156.98	-35.61	-65.56	170	18
700	0.01	69.78	67.68	147.44	-42.41	-62.87	202	9
	Scale 1 + 3							
1	0.35	-309.48	68.92	-192.45	-501.99	-444.56	-174	38
5	0.36	-296.03	63.68	-173.23	-405.35	-420.84	-171	37
10	0.35	-292.56	64.17	-170.81	-403.00	-418.33	-167	37
20	0.35	-287.05	64.49	-163.42	-399.10	-413.44	-161	37
30	0.35	-282.34	64.44	-155.94	-396.02	-408.63	-156	37
40	0.35	-279.02	64.34	-155.94	-392.98	-405.12	-153	37
50	0.35	-276.51	64.46	-151.05	-390.76	-402.85	-150	37
60	0.35	-274.22	64.52	-146.26	-390.04	-400.67	-148	37
70	0.34	-271.92	64.96	-143.87	-387.97	-399.24	-145	37
80	0.34	-270.14	65.01	-139.17	-386.66	-397.57	-143	37
90	0.37	-266.34	62.76	-139.17	-386.04	-389.35	-143	37
100	0.36	-264.32	63.33	-134.67	-385.43	-388.46	-140	37
150	0.34	-256.47	64.89	-124.57	-380.91	-383.64	-129	37
200	0.31	-248.38	66.28	-109.14	-378.35	-378.28	-118	37
250	0.23	-233.21	71.68	-71.43	-373.44	-373.69	-93	37
300	0.01	-207.50	87.96	-5.82	-357.74	-379.89	-35	35
350	0.06	-160.41	101.61	34.30	-340.96	-359.56	39	32
400	0.03	-126.80	105.78	53.66	-316.73	-334.11	81	29
450	0.00	-86.81	101.95	83.96	-253.66	-286.62	113	26
500	0.00	-61.53	109.33	104.00	-268.71	-275.81	153	20
550	0.00	-47.79	96.42	122.97	-199.51	-236.77	141	17
600	0.20	-32.97	121.50	148.04	-192.64	-271.11	205	9
650	0.89	53.17	79.12	164.25	-29.34	-101.91	208	6
700	1.00	169.84	24.32	187.04	152.65	122.18	218	2

Wt_Threshold (lbs)	r^2	mean diff (lbs)	stdev diff (lbs)	max diff (lbs)	min diff (lbs)	lower limit (lbs)	upper limit (lbs)	Sample Size
	Scale 1 + 2 + 3							
1	0.61	-172.47	48.65	-40.59	-287.89	-267.81	-77	38
5	0.60	-158.28	48.63	-34.32	-262.27	-253.59	-63	38
10	0.60	-152.62	48.77	-27.96	-262.27	-248.20	-57	38
20	0.60	-143.95	48.72	-21.56	-262.27	-239.44	-48	38
30	0.61	-135.55	47.86	-15.09	-262.27	-229.35	-42	38
40	0.61	-129.65	47.84	-8.57	-262.27	-223.41	-36	38
50	0.60	-125.53	48.46	-8.57	-262.27	-220.51	-31	38
60	0.59	-121.77	49.07	-2.09	-262.27	-217.95	-26	38
70	0.58	-117.80	49.76	-2.09	-262.27	-215.32	-20	38
80	0.57	-114.90	50.54	4.25	-262.27	-213.97	-16	38
90	0.67	-108.03	44.48	4.25	-187.66	-195.20	-21	38
100	0.65	-104.51	45.70	10.37	-185.07	-194.09	-15	38
150	0.60	-89.02	48.71	16.24	-172.72	-184.48	6	38
200	0.58	-69.53	50.63	33.41	-161.42	-168.75	30	38
250	0.53	-39.78	53.72	86.90	-150.29	-145.07	66	38
300	0.45	-14.25	56.99	115.16	-124.41	-125.95	97	38
350	0.44	7.85	57.39	137.71	-107.88	-104.62	120	38
400	0.41	33.41	60.56	158.78	-94.70	-85.29	152	38
450	0.41	54.54	62.59	171.34	-88.44	-68.13	177	38
500	0.39	71.64	63.73	185.42	-83.53	-53.25	197	38
550	0.24	102.67	70.45	256.66	-26.85	-35.41	241	38
600	0.13	134.06	75.28	279.05	-23.17	-13.49	282	38
650	0.11	161.08	80.70	302.43	-30.31	2.91	319	36
700	0.07	197.57	80.91	333.96	103.31	38.99	356	32

APPENDIX K

FFT TABLES 3 – SCALE BEEF CATTLE

	Source	r2	mean diff	stdev diff	upper limit	lower limit	sample size
DC	Scale 1 + 2 + 3	0.27	-286.84	76.61	-136.69	-436.99	33
	Scale 1 + 2	0.22	-381.16	69.62	-244.70	-517.61	33
	Scale 1 + 3	0.25	-385.41	72.65	-243.01	-527.80	33
	Scale 2 + 3	0.21	-370.39	71.60	-230.07	-510.72	33
	Scale 1	0.23	-480.70	68.11	-347.21	-614.19	33
	Scale 2	0.06	-464.24	76.24	-314.81	-613.67	33
	Scale 3	0.19	-466.94	70.55	-328.67	-605.21	33
DC + 1	Scale 1 + 2 + 3	0.27	-227.93	70.47	-89.80	-366.06	33
	Scale 1 + 2	0.32	-283.10	65.56	-154.61	-411.58	33
	Scale 1 + 3	0.12	-382.92	82.33	-221.56	-544.28	33
	Scale 2 + 3	0.41	-303.18	59.44	-186.68	-419.68	33
	Scale 1	0.33	-495.07	66.49	-364.75	-625.40	33
	Scale 2	0.08	-483.91	74.04	-338.80	-629.02	33
	Scale 3	0.27	-489.16	66.79	-358.26	-620.07	33
Max Amplitude	Scale 1 + 2 + 3	0.53	-214.28	52.76	-110.87	-317.70	33
	Scale 1 + 2	0.36	-281.66	62.18	-159.80	-403.52	33
	Scale 1 + 3	0.30	-358.87	67.72	-226.14	-491.61	33
	Scale 2 + 3	0.43	-300.27	58.18	-186.25	-414.30	33
	Scale 1	0.23	-480.70	68.11	-347.21	-614.19	33
	Scale 2	0.06	-464.24	76.24	-314.81	-613.67	33
	Scale 3	0.19	-466.94	70.55	-328.67	-605.21	33

APPENDIX L

RMS 3 – SCALE BEEF CATTLE

Wt_Threshold (lbs)	r^2	mean diff (lbs)	stdev diff (lbs)	max diff (lbs)	min diff (lbs)	lower limit (lbs)	upper limit (lbs)	Sample Size
					Scale 1			
1	0.39	-327.13	61.33	-218.69	-452.17	-447.34	-206.92	37
5	0.42	-321.19	59.64	-214.52	-449.00	-438.09	-204.29	37
10	0.41	-318.80	60.05	-211.42	-447.37	-436.50	-201.10	37
					Scale 2			
1	0.23	-311.18	69.19	-159.18	-476.08	-446.79	-175.58	38
5	0.20	-302.06	72.13	-147.75	-475.05	-443.43	-160.69	38
10	0.17	-297.56	74.00	-135.10	-474.00	-442.61	-152.52	38
					Scale 3			
1	0.42	-317.09	62.44	-184.64	-501.08	-439.48	-194.71	37
5	0.49	-307.16	55.61	-177.50	-437.10	-416.15	-198.17	36
10	0.49	-303.90	55.78	-169.78	-435.75	-413.23	-194.58	36
					Scale 1 + 2			
1	0.67	-158.93	43.91	-84.20	-280.89	-244.99	-72.86	38
5	0.61	-145.33	47.59	-69.25	-278.49	-238.62	-52.05	38
10	0.59	-140.73	48.91	-56.34	-276.03	-236.59	-44.87	38
					Scale 2 + 3			
1	0.64	-200.22	45.84	-110.16	-302.08	-290.06	-110.38	38
5	0.62	-193.58	47.38	-107.18	-299.94	-286.44	-100.72	38
10	0.61	-189.87	47.85	-103.30	-297.77	-283.66	-96.09	38
					Scale 1 + 3			
1	0.31	-278.29	74.67	-150.00	-500.93	-424.64	-131.94	38
5	0.32	-267.38	67.36	-136.74	-388.04	-399.41	-135.35	37
10	0.32	-265.39	67.70	-135.30	-386.74	-398.08	-132.70	37
					Scale 1 + 2 + 3			
1	0.67	-103.35	44.55	14.92	-191.70	-190.67	-16.03	38
5	0.63	-94.59	46.41	18.51	-188.83	-185.56	-3.62	38
10	0.63	-91.22	46.56	22.18	-185.91	-182.47	0.03	38

APPENDIX M

SUCCESSIVE INCREASE/DECREASE IN DATA VALUES 3 SCALE DAIRY CATTLE

m_threshold	r^2	mean diff (lbs)	stdev diff (lbs)	max diff (lbs)	min diff (lbs)	lower limit (lbs)	upper limit (lbs)	Sample Size
	Scale 1							
5	0.06	-1213.41	353.27	-340.97	-1660.85	-1905.80	-521.01	26
6	0.01	-1184.79	368.00	-341.00	-1660.85	-1906.06	-463.52	26
7	0.04	-1168.36	358.05	-341.00	-1613.44	-1870.14	-466.59	26
8	0.09	-1104.55	346.42	-324.12	-1611.07	-1783.51	-425.59	26
9	0.04	-1073.89	357.64	-174.86	-1610.98	-1774.84	-372.94	26
10	0.07	-1056.29	350.26	-172.59	-1610.97	-1742.78	-369.79	26
11	0.07	-1052.28	349.70	-170.47	-1611.04	-1737.69	-366.88	26
12	0.10	-1029.76	343.88	-160.19	-1506.61	-1703.75	-355.77	26
13	0.09	-1020.66	345.47	-158.56	-1504.53	-1697.76	-343.56	26
14	0.10	-1016.77	343.65	-156.99	-1502.47	-1690.31	-343.23	26
15	0.09	-1011.87	344.24	-155.49	-1500.41	-1686.56	-337.18	26
16	0.14	-1004.38	335.88	-154.08	-1497.98	-1662.70	-346.07	26
17	0.11	-994.71	340.66	-152.76	-1496.77	-1662.40	-327.02	26
18	0.03	-975.99	360.96	-148.54	-1495.74	-1683.46	-268.52	27
19	0.05	-962.94	354.65	-147.54	-1494.88	-1658.05	-267.84	27
20	0.04	-959.50	354.89	-146.58	-1494.18	-1655.08	-263.92	27
21	0.04	-959.71	355.43	-145.70	-1493.66	-1656.35	-263.07	27
22	0.10	-948.20	344.93	-144.86	-1493.31	-1624.25	-272.15	27
23	0.14	-923.68	338.09	-146.43	-1493.12	-1586.34	-261.03	27
24	0.14	-922.68	338.04	-146.39	-1493.08	-1585.22	-260.14	27
25	0.12	-926.37	343.59	-146.41	-1493.15	-1599.79	-252.95	26
26	0.18	-921.08	336.61	-146.49	-1425.69	-1580.83	-261.34	26
27	0.16	-912.99	338.53	-146.62	-1426.40	-1576.50	-249.47	26
28	0.15	-910.33	339.72	-146.79	-1427.53	-1576.18	-244.49	26
29	0.15	-911.77	338.95	-147.00	-1429.10	-1576.10	-247.45	26
30	0.12	-915.79	343.15	-147.24	-1431.10	-1588.35	-243.23	26
	Scale 2							
5	0.00	-1122.23	379.34	-158.53	-1625.43	-1865.72	-378.75	27
6	0.00	-1108.91	369.67	-152.05	-1625.35	-1833.45	-384.36	27
7	0.03	-1087.27	362.46	-145.96	-1625.35	-1797.68	-376.87	27
8	0.05	-1080.16	355.43	-140.33	-1554.73	-1776.80	-383.53	27
9	0.05	-1075.89	355.96	-135.16	-1554.10	-1773.56	-378.23	27
10	0.05	-1071.84	356.37	-130.39	-1553.56	-1770.32	-373.36	27
11	0.05	-1059.03	355.25	-126.02	-1553.14	-1755.30	-362.76	27
12	0.06	-1053.38	354.46	-122.11	-1552.83	-1748.10	-358.65	27
13	0.06	-1050.01	354.47	-118.67	-1552.60	-1744.76	-355.27	27
14	0.07	-1038.23	351.53	-115.60	-1552.47	-1727.22	-349.25	27
15	0.07	-1035.28	351.40	-112.91	-1552.42	-1724.02	-346.54	27
16	0.06	-1022.20	353.16	-110.56	-1552.41	-1714.39	-330.02	27
17	0.07	-1017.18	350.31	-108.55	-1552.46	-1703.77	-330.58	27
18	0.08	-1014.94	349.91	-106.88	-1552.57	-1700.74	-329.13	27
19	0.08	-1012.96	349.42	-105.55	-1552.71	-1697.81	-328.10	27
20	0.11	-1006.01	344.41	-104.60	-1552.91	-1681.05	-330.98	27
21	0.11	-1004.64	343.85	-104.08	-1553.15	-1678.57	-330.71	27
22	0.12	-1004.16	342.96	-104.02	-1553.43	-1676.35	-331.96	27
23	0.12	-1002.78	341.95	-104.51	-1553.74	-1672.98	-332.58	27
24	0.13	-999.72	341.12	-105.58	-1554.11	-1668.30	-331.14	27
25	0.15	-997.22	337.82	-107.21	-1554.53	-1659.34	-335.10	27
26	0.13	-998.90	339.88	-109.45	-1564.53	-1665.04	-332.75	27
27	0.24	-1007.81	324.40	-112.31	-1572.57	-1643.63	-371.99	27
28	0.25	-1007.48	323.31	-115.78	-1572.84	-1641.15	-373.81	27
29	0.26	-1007.30	322.14	-119.85	-1573.16	-1638.69	-375.92	27
30	0.30	-1015.19	315.78	-124.52	-1573.54	-1634.12	-396.27	27

m_threshold	r²	mean diff (lbs)	stdev diff (lbs)	max diff (lbs)	min diff (lbs)	lower limit (lbs)	upper limit (lbs)	Sample Size
	Scale 3							
5	0.15	-1227.93	346.68	-340.69	-1661.93	-1907.41	-548.45	20
6	0.13	-1214.84	348.22	-340.69	-1661.93	-1897.33	-532.34	20
7	0.14	-1202.07	345.98	-340.69	-1661.93	-1880.17	-523.96	20
8	0.29	-1141.83	329.86	-340.69	-1575.32	-1788.34	-495.32	22
9	0.30	-1137.67	327.69	-340.69	-1575.06	-1779.92	-495.41	22
10	0.25	-1154.92	290.02	-341.04	-1575.06	-1723.35	-586.49	21
11	0.25	-1138.73	290.16	-341.04	-1575.06	-1707.43	-570.04	21
12	0.26	-1127.94	290.85	-298.76	-1575.06	-1698.00	-557.88	22
13	0.27	-1125.44	289.93	-298.23	-1566.79	-1693.70	-557.18	23
14	0.42	-1106.60	282.62	-297.71	-1440.16	-1660.53	-552.66	23
15	0.30	-1095.94	289.25	-297.21	-1437.91	-1662.87	-529.02	23
16	0.41	-1084.72	284.63	-296.72	-1435.81	-1642.58	-526.85	23
17	0.41	-1083.64	284.77	-296.25	-1433.87	-1641.78	-525.50	23
18	0.40	-1081.65	285.56	-295.80	-1432.07	-1641.34	-521.96	23
19	0.38	-1076.99	286.33	-295.38	-1430.41	-1638.19	-515.78	23
20	0.37	-1074.05	287.15	-295.01	-1428.94	-1636.86	-511.24	23
21	0.36	-1072.15	287.62	-294.67	-1427.68	-1635.87	-508.42	23
22	0.33	-1066.84	290.29	-294.36	-1426.66	-1635.79	-497.88	23
23	0.32	-1065.39	291.31	-284.60	-1425.92	-1636.34	-494.44	23
24	0.36	-1062.89	289.33	-284.24	-1425.51	-1629.97	-495.81	23
25	0.36	-1062.13	289.34	-283.88	-1425.45	-1629.23	-495.03	23
26	0.26	-1051.95	298.41	-283.52	-1425.76	-1636.84	-467.07	22
27	0.16	-1046.78	311.26	-182.34	-1426.48	-1656.85	-436.72	22
28	0.21	-1051.38	308.28	-172.72	-1427.61	-1655.60	-447.17	22
29	0.21	-1051.09	306.57	-189.91	-1429.18	-1651.95	-450.22	22
30	0.19	-1051.13	309.79	-190.04	-1431.17	-1658.30	-443.95	22
	Scale 1 + 2							
5	0.07	-1175.80	356.50	-249.76	-1609.01	-1874.54	-477.07	27
6	0.06	-1173.33	356.75	-246.52	-1608.54	-1872.54	-474.12	27
7	0.06	-1169.84	357.15	-243.48	-1608.13	-1869.84	-469.84	27
8	0.05	-1168.90	357.06	-240.66	-1607.78	-1868.74	-469.07	27
9	0.05	-1166.70	357.21	-238.08	-1607.47	-1866.83	-466.58	27
10	0.05	-1164.62	357.32	-235.69	-1607.20	-1864.96	-464.29	27
11	0.04	-1159.71	357.71	-233.51	-1606.99	-1860.81	-458.61	27
12	0.05	-1156.31	356.91	-231.55	-1606.83	-1855.83	-456.79	27
13	0.05	-1154.64	356.86	-229.83	-1606.72	-1854.08	-455.20	27
14	0.08	-1150.02	354.05	-228.30	-1606.66	-1843.94	-456.10	27
15	0.08	-1148.69	353.86	-226.95	-1606.63	-1842.25	-455.13	27
16	0.07	-1142.66	354.85	-225.78	-1606.63	-1838.15	-447.17	27
17	0.08	-1140.49	353.59	-224.78	-1606.65	-1833.51	-447.47	27
18	0.08	-1139.52	353.33	-223.94	-1606.71	-1832.03	-447.00	27
19	0.09	-1138.66	353.03	-223.28	-1606.78	-1830.59	-446.73	27
20	0.10	-1136.34	351.53	-222.80	-1606.88	-1825.33	-447.35	27
21	0.10	-1135.77	351.18	-222.54	-1607.00	-1824.06	-447.47	27
22	0.11	-1135.63	350.60	-222.51	-1607.14	-1822.79	-448.47	27
23	0.12	-1135.05	349.99	-222.75	-1607.29	-1821.02	-449.07	27
24	0.07	-1129.21	353.09	-223.29	-1607.48	-1821.25	-437.17	27
25	0.09	-1128.02	351.48	-224.10	-1607.69	-1816.90	-439.14	27
26	0.13	-1125.88	348.14	-225.22	-1607.92	-1808.22	-443.53	27
27	0.24	-1128.48	340.94	-226.65	-1543.70	-1796.71	-460.25	27
28	0.24	-1128.27	340.25	-228.39	-1543.35	-1795.15	-461.38	27
29	0.23	-1126.23	340.84	-230.42	-1542.99	-1794.27	-458.19	27
30	0.24	-1129.09	340.21	-232.75	-1542.64	-1795.88	-462.29	27

m_threshold	r²	mean diff (lbs)	stdev diff (lbs)	max diff (lbs)	min diff (lbs)	lower limit (lbs)	upper limit (lbs)	Sample Size
	Scale 2 + 3							
5	0.05	-1175.75	358.35	-249.73	-1609.69	-1878.10	-473.41	27
6	0.06	-1171.09	357.29	-246.49	-1609.22	-1871.37	-470.81	27
7	0.05	-1167.62	357.64	-243.44	-1608.81	-1868.58	-466.66	27
8	0.05	-1166.70	357.52	-240.63	-1608.46	-1867.42	-465.98	27
9	0.05	-1164.52	357.62	-238.04	-1608.14	-1865.44	-463.59	27
10	0.05	-1162.45	357.68	-235.66	-1607.87	-1863.50	-461.41	27
11	0.05	-1159.32	356.92	-233.47	-1607.66	-1858.87	-459.78	27
12	0.06	-1156.56	356.62	-231.52	-1607.50	-1855.52	-457.61	27
13	0.06	-1154.56	356.20	-229.79	-1607.38	-1852.71	-456.41	27
14	0.07	-1149.13	354.67	-228.26	-1607.32	-1844.27	-453.99	27
15	0.07	-1147.72	354.54	-226.91	-1607.29	-1842.61	-452.83	27
16	0.06	-1141.24	355.82	-225.74	-1607.28	-1838.64	-443.84	27
17	0.07	-1139.01	354.61	-224.74	-1607.30	-1834.04	-443.98	27
18	0.07	-1137.97	354.40	-223.90	-1607.35	-1832.59	-443.35	27
19	0.07	-1137.05	354.15	-223.23	-1607.43	-1831.17	-442.93	27
20	0.08	-1134.67	352.69	-222.76	-1607.52	-1825.94	-443.40	27
21	0.09	-1134.03	352.38	-222.50	-1607.64	-1824.69	-443.38	27
22	0.09	-1133.84	351.85	-222.47	-1607.77	-1823.45	-444.23	27
23	0.10	-1133.19	351.29	-222.71	-1607.93	-1821.70	-444.69	27
24	0.10	-1131.71	350.79	-223.25	-1608.11	-1819.24	-444.18	27
25	0.12	-1130.51	349.18	-224.06	-1608.32	-1814.88	-446.13	27
26	0.11	-1131.39	349.95	-225.18	-1613.34	-1817.28	-445.50	27
27	0.21	-1134.19	342.95	-226.62	-1617.37	-1806.36	-462.01	27
28	0.21	-1134.07	342.38	-228.35	-1617.50	-1805.13	-463.01	27
29	0.22	-1133.96	341.71	-230.38	-1617.66	-1803.71	-464.21	27
30	0.24	-1138.99	340.12	-232.72	-1617.85	-1805.61	-472.37	27
	Scale 1 + 3							
5	0.13	-1197.90	352.02	-280.15	-1626.73	-1887.85	-507.95	27
6	0.13	-1195.37	352.23	-277.99	-1626.42	-1885.74	-505.01	27
7	0.15	-1191.36	350.97	-275.96	-1626.15	-1879.24	-503.49	27
8	0.15	-1190.08	350.66	-274.08	-1625.91	-1877.36	-502.80	27
9	0.14	-1186.93	351.00	-272.36	-1625.70	-1874.87	-498.98	27
10	0.14	-1185.36	350.92	-270.77	-1625.52	-1873.14	-497.58	27
11	0.14	-1183.49	350.66	-269.31	-1625.38	-1870.77	-496.21	27
12	0.15	-1181.10	349.99	-268.01	-1625.28	-1867.06	-495.14	27
13	0.16	-1179.62	349.59	-266.86	-1625.20	-1864.80	-494.44	27
14	0.18	-1176.69	347.68	-265.84	-1625.16	-1858.14	-495.24	27
15	0.18	-1175.70	347.45	-264.94	-1625.14	-1856.68	-494.71	27
16	0.18	-1171.58	348.02	-264.16	-1625.14	-1853.69	-489.48	27
17	0.20	-1170.20	347.13	-263.49	-1625.15	-1850.55	-489.85	27
18	0.20	-1169.48	346.87	-262.93	-1625.19	-1849.34	-489.62	27
19	0.20	-1168.85	346.60	-262.49	-1625.23	-1848.16	-489.53	27
20	0.22	-1167.24	345.43	-262.17	-1625.30	-1844.27	-490.21	27
21	0.22	-1166.80	345.13	-262.00	-1625.37	-1843.24	-490.36	27
22	0.23	-1166.66	344.67	-261.98	-1625.47	-1842.20	-491.11	27
23	0.24	-1166.27	344.24	-262.14	-1625.57	-1840.97	-491.56	27
24	0.19	-1162.33	346.07	-262.50	-1625.69	-1840.63	-484.04	27
25	0.21	-1161.52	344.94	-263.04	-1625.83	-1837.59	-485.45	27
26	0.26	-1160.06	342.65	-263.79	-1625.98	-1831.64	-488.48	27
27	0.37	-1160.99	338.25	-264.74	-1583.15	-1823.95	-498.04	27
28	0.37	-1160.88	337.81	-265.90	-1582.92	-1822.99	-498.78	27
29	0.37	-1159.46	338.13	-267.25	-1582.68	-1822.19	-496.74	27
30	0.40	-1162.44	338.33	-268.81	-1582.45	-1825.56	-499.32	27

m_threshold	r²	mean diff (lbs)	stdev diff (lbs)	max diff (lbs)	min diff (lbs)	lower limit (lbs)	upper limit (lbs)	Sample Size
	Scale 1 + 2 + 3							
5	0.05	-1100.56	356.18	-158.66	-1556.06	-1798.65	-402.47	27
6	0.04	-1093.52	357.19	-152.18	-1555.12	-1793.60	-393.44	27
7	0.06	-1082.01	354.35	-146.09	-1554.30	-1776.52	-387.49	27
8	0.06	-1078.65	354.99	-140.46	-1553.60	-1774.41	-382.88	27
9	0.05	-1069.67	356.26	-135.29	-1552.97	-1767.93	-371.42	27
10	0.04	-1065.42	356.78	-130.52	-1552.43	-1764.69	-366.15	27
11	0.05	-1060.22	356.42	-126.15	-1552.01	-1758.79	-361.65	27
12	0.05	-1053.45	354.77	-122.25	-1551.69	-1748.79	-358.11	27
13	0.06	-1049.35	354.31	-118.80	-1551.46	-1743.79	-354.92	27
14	0.08	-1040.90	350.20	-115.74	-1551.33	-1727.27	-354.53	27
15	0.08	-1038.22	350.06	-113.04	-1551.27	-1724.33	-352.11	27
16	0.07	-1026.17	351.39	-110.70	-1551.26	-1714.89	-337.45	27
17	0.08	-1021.83	348.96	-108.69	-1551.31	-1705.79	-337.88	27
18	0.09	-1019.88	348.62	-107.02	-1551.41	-1703.15	-336.61	27
19	0.09	-1018.17	348.18	-105.69	-1551.55	-1700.58	-335.76	27
20	0.10	-1013.53	345.78	-104.74	-1551.74	-1691.24	-335.82	27
21	0.10	-1012.37	345.21	-104.22	-1551.98	-1688.97	-335.77	27
22	0.11	-1012.09	344.31	-104.16	-1552.25	-1686.92	-337.26	27
23	0.12	-1011.05	343.38	-104.65	-1552.56	-1684.06	-338.04	27
24	0.07	-999.38	350.84	-105.71	-1552.92	-1687.02	-311.74	27
25	0.09	-997.03	347.75	-107.34	-1553.34	-1678.60	-315.45	27
26	0.13	-992.73	340.72	-109.58	-1553.80	-1660.52	-324.93	27
27	0.24	-995.57	326.32	-112.44	-1426.45	-1635.15	-355.99	27
28	0.24	-995.27	325.25	-115.91	-1427.59	-1632.76	-357.78	27
29	0.23	-991.02	326.25	-119.98	-1429.16	-1630.45	-351.59	27
30	0.24	-997.38	325.35	-124.65	-1431.15	-1635.06	-359.71	27

APPENDIX N

AVERAGE EVERYTHING BETWEEN REGRESSION 3 SCALE DAIRY CATTLE

Wt_Threshold (lbs)	r^2	mean diff (lbs)	stdev diff (lbs)	max diff (lbs)	min diff (lbs)	lower limit (lbs)	upper limit (lbs)	Sample Size
	Scale 1							
1	0.00	-972.71	371.16	0.89	-1564.18	-1700.17	-245.24	27
5	0.07	-952.85	353.04	12.17	-1385.61	-1644.79	-260.91	27
10	0.07	-950.51	352.81	13.09	-1380.02	-1642.00	-259.03	27
20	0.07	-944.19	353.06	14.45	-1372.71	-1636.18	-252.20	27
30	0.08	-939.19	350.71	15.78	-1366.10	-1626.57	-251.80	27
40	0.08	-935.74	350.56	17.07	-1362.81	-1622.83	-248.65	27
50	0.08	-930.43	351.16	17.91	-1357.90	-1618.68	-242.17	27
60	0.08	-926.73	351.24	18.32	-1355.12	-1615.15	-238.30	27
70	0.07	-924.90	351.38	19.13	-1353.97	-1613.58	-236.21	27
80	0.08	-923.05	351.22	20.67	-1352.34	-1611.44	-234.67	27
90	0.07	-921.24	351.40	21.43	-1350.79	-1609.97	-232.52	27
100	0.07	-918.48	351.99	22.52	-1349.82	-1608.37	-228.59	27
150	0.07	-901.93	351.84	28.44	-1346.31	-1591.52	-212.34	27
200	0.04	-889.23	356.55	35.61	-1344.00	-1588.06	-190.41	27
250	0.08	-859.59	349.70	37.64	-1323.32	-1544.99	-174.20	27
300	0.01	-862.45	339.72	86.50	-1323.76	-1528.30	-196.61	26
350	0.00	-843.44	333.44	91.82	-1295.22	-1496.96	-189.91	26
400	0.04	-857.95	348.52	94.10	-1295.30	-1541.04	-174.85	23
450	0.05	-832.62	360.47	108.93	-1290.37	-1539.14	-126.11	22
500	0.00	-811.85	349.65	108.42	-1291.22	-1497.15	-126.56	22
550	0.03	-757.02	354.60	100.43	-1293.00	-1452.02	-62.01	18
600	0.10	-693.21	347.15	78.04	-1297.56	-1373.61	-12.81	16
650	0.02	-635.30	434.17	368.30	-1299.77	-1486.25	215.65	13
700	0.09	-591.82	435.14	386.17	-1058.21	-1444.68	261.03	11
	Scale 2							
1	0.25	-1077.00	328.06	-198.34	-1610.53	-1719.99	-434.02	27
5	0.25	-1076.01	327.84	-197.90	-1610.36	-1718.56	-433.47	27
10	0.25	-1075.35	327.66	-197.62	-1610.20	-1717.56	-433.14	27
20	0.25	-1074.19	327.42	-197.02	-1610.02	-1715.91	-432.47	27
30	0.25	-1073.02	327.45	-196.34	-1609.76	-1714.82	-431.23	27
40	0.25	-1071.67	327.46	-195.01	-1609.67	-1713.49	-429.86	27
50	0.25	-1071.10	327.38	-194.63	-1609.63	-1712.75	-429.44	27
60	0.25	-1068.79	327.56	-192.28	-1609.65	-1710.79	-426.79	27
70	0.25	-1068.32	327.69	-189.62	-1609.72	-1710.59	-426.05	27
80	0.25	-1068.00	327.65	-189.28	-1609.83	-1710.18	-425.81	27
90	0.25	-1067.59	327.69	-187.33	-1609.99	-1709.84	-425.33	27
100	0.24	-1067.07	327.84	-184.41	-1610.21	-1709.62	-424.51	27
150	0.23	-1062.15	328.66	-175.59	-1613.25	-1706.31	-417.99	27
200	0.24	-1035.38	333.69	-175.72	-1478.58	-1689.40	-381.36	26
250	0.21	-1034.88	339.02	-167.04	-1479.37	-1699.35	-370.42	25
300	0.08	-998.30	359.91	-168.78	-1482.03	-1703.71	-292.90	23
350	0.00	-958.37	345.29	-174.57	-1432.60	-1635.12	-281.61	22
400	0.12	-916.87	395.10	108.14	-1436.24	-1691.26	-142.48	21
450	0.02	-855.09	388.87	122.20	-1411.23	-1617.26	-92.92	19
500	0.00	-945.65	276.23	-519.74	-1420.36	-1487.05	-404.26	14
550	0.00	-911.89	208.21	-605.11	-1356.42	-1319.98	-503.80	12
600	0.60	-815.82	134.11	-590.72	-951.53	-1078.68	-552.96	9
650	0.24	-778.91	160.36	-481.68	-931.92	-1093.22	-464.61	8
700	0.52	-701.12	179.44	-460.57	-914.15	-1052.81	-349.42	5

Wt_Threshold (lbs)	r^2	mean diff (lbs)	stdev diff (lbs)	max diff (lbs)	min diff (lbs)	lower limit (lbs)	upper limit (lbs)	Sample Size
	Scale 3							
1	0.04	-1068.49	317.32	-202.27	-1522.10	-1690.43	-446.55	23
5	0.04	-1055.23	317.84	-201.27	-1522.01	-1678.19	-432.27	23
10	0.04	-1053.99	318.07	-199.81	-1521.91	-1677.40	-430.59	23
20	0.03	-1051.53	319.05	-193.85	-1521.75	-1676.85	-426.20	23
30	0.03	-1049.62	319.57	-192.64	-1521.61	-1675.97	-423.28	23
40	0.03	-1048.07	319.78	-191.96	-1521.48	-1674.83	-421.30	23
50	0.03	-1043.88	319.64	-191.34	-1521.42	-1670.36	-417.39	23
60	0.03	-1041.91	320.52	-190.59	-1521.33	-1670.11	-413.71	23
70	0.03	-1040.56	320.84	-190.08	-1521.25	-1669.41	-411.72	23
80	0.03	-1039.26	320.82	-189.32	-1521.20	-1668.06	-410.45	23
90	0.03	-1037.83	320.72	-187.67	-1521.15	-1666.43	-409.22	23
100	0.02	-1035.93	321.69	-181.89	-1521.14	-1666.43	-405.44	23
150	0.01	-1016.84	324.33	-179.87	-1521.46	-1652.51	-381.17	23
200	0.00	-1001.65	329.59	-175.99	-1522.41	-1647.64	-355.67	23
250	0.00	-967.82	344.33	-64.27	-1463.07	-1642.69	-292.95	22
300	0.06	-1022.63	294.70	-626.70	-1465.31	-1600.24	-445.03	18
350	0.14	-989.98	303.91	-585.02	-1467.29	-1585.63	-394.33	18
400	0.06	-925.94	303.12	-518.38	-1468.94	-1520.04	-331.83	16
450	0.01	-889.28	297.48	-512.51	-1470.98	-1472.33	-306.24	15
500	0.11	-822.83	235.27	-504.07	-1146.01	-1283.95	-361.70	11
550	0.12	-815.21	256.36	-429.24	-1040.11	-1317.68	-312.75	8
600	0.03	-774.59	260.06	-412.48	-1049.69	-1284.30	-264.88	7
650	0.00	-732.29	239.88	-396.78	-971.36	-1202.44	-262.15	7
700	0.06	-692.22	245.79	-381.61	-931.43	-1173.96	-210.47	4
	Scale 1 + 2							
1	0.20	-1100.72	341.08	-200.60	-1579.73	-1769.22	-432.22	27
5	0.20	-1099.90	340.97	-200.10	-1579.26	-1768.20	-431.60	27
10	0.20	-1098.66	340.61	-199.47	-1578.81	-1766.24	-431.08	27
20	0.19	-1096.95	341.17	-197.21	-1577.81	-1765.64	-428.27	27
30	0.18	-1094.50	341.62	-193.84	-1577.31	-1764.07	-424.94	27
40	0.18	-1093.63	341.98	-190.13	-1576.69	-1763.89	-423.37	27
50	0.17	-1092.68	342.57	-181.92	-1576.33	-1764.11	-421.26	27
60	0.15	-1089.24	343.98	-168.47	-1575.95	-1763.43	-415.06	27
70	0.15	-1087.97	343.80	-168.11	-1572.45	-1761.80	-414.14	27
80	0.15	-1084.49	343.55	-167.71	-1569.04	-1757.83	-411.15	27
90	0.15	-1081.63	344.18	-167.35	-1569.00	-1756.21	-407.05	27
100	0.10	-1068.82	348.59	-166.92	-1536.89	-1752.05	-385.58	27
150	0.09	-1045.88	348.19	-156.11	-1494.68	-1728.32	-363.44	27
200	0.03	-1010.20	359.22	-139.94	-1472.28	-1714.25	-306.15	27
250	0.06	-1007.11	351.59	-24.60	-1474.09	-1696.21	-318.01	25
300	0.10	-997.84	361.11	-23.07	-1483.53	-1705.60	-290.08	24
350	0.00	-939.32	333.21	-23.24	-1486.75	-1592.41	-286.23	22
400	0.20	-884.77	306.18	-28.09	-1255.54	-1484.87	-284.67	21
450	0.07	-799.63	382.23	76.22	-1256.41	-1548.79	-50.47	11
500	0.01	-906.89	264.87	-576.79	-1258.85	-1426.02	-387.76	8
550	0.06	-865.22	229.52	-569.55	-1172.57	-1315.07	-415.38	8
600	0.00	-868.00	243.66	-509.34	-1176.21	-1345.57	-390.43	6
650	0.83	-821.31	198.29	-468.62	-936.18	-1209.95	-432.66	5
700	0.12	-888.69	23.10	-866.41	-920.86	-933.97	-843.42	4

Wt_Threshold (lbs)	r^2	mean diff (lbs)	stdev diff (lbs)	max diff (lbs)	min diff (lbs)	lower limit (lbs)	upper limit (lbs)	Sample Size
	Scale 2 + 3							
1	0.17	-1142.79	347.48	-257.91	-1577.88	-1823.83	-461.75	27
5	0.17	-1142.38	347.43	-257.65	-1577.88	-1823.33	-461.43	27
10	0.17	-1142.05	347.45	-256.77	-1577.88	-1823.03	-461.06	27
20	0.17	-1141.46	347.25	-256.54	-1576.07	-1822.06	-460.85	27
30	0.18	-1140.10	346.53	-256.33	-1575.83	-1819.28	-460.92	27
40	0.18	-1139.74	346.39	-256.12	-1575.67	-1818.65	-460.83	27
50	0.18	-1139.12	346.33	-254.45	-1575.25	-1817.90	-460.33	27
60	0.16	-1136.51	346.82	-250.16	-1571.52	-1816.27	-456.76	27
70	0.16	-1135.94	346.81	-250.09	-1571.20	-1815.67	-456.20	27
80	0.16	-1134.51	347.03	-249.54	-1570.38	-1814.68	-454.33	27
90	0.16	-1133.97	346.96	-249.17	-1570.33	-1814.00	-453.94	27
100	0.07	-1121.98	353.55	-249.18	-1570.34	-1814.92	-429.05	27
150	0.08	-1117.27	355.01	-250.21	-1572.06	-1813.07	-421.47	26
200	0.01	-1135.59	339.22	-254.58	-1510.18	-1800.45	-470.73	23
250	0.04	-1175.96	279.00	-755.92	-1492.55	-1722.80	-629.13	18
300	0.02	-1156.73	263.90	-694.88	-1493.46	-1673.96	-639.50	16
350	0.01	-1088.26	252.76	-677.84	-1495.40	-1583.67	-592.85	15
400	0.01	-1037.56	246.36	-665.81	-1303.06	-1520.42	-554.70	10
450	0.46	-975.23	211.79	-664.10	-1206.31	-1390.34	-560.12	6
500	1.00	-816.29	229.29	-617.55	-1067.16	-1265.69	-366.88	3
550	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1
600	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1
650	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
700	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
	Scale 1 + 3							
1	0.24	-1132.13	342.40	-243.69	-1569.71	-1803.22	-461.04	27
5	0.24	-1131.59	342.37	-242.39	-1569.29	-1802.63	-460.56	27
10	0.23	-1130.74	342.01	-242.13	-1569.05	-1801.06	-460.41	27
20	0.23	-1129.74	341.95	-241.73	-1568.69	-1799.96	-459.52	27
30	0.24	-1129.13	341.77	-241.12	-1568.12	-1798.99	-459.28	27
40	0.20	-1126.18	343.34	-231.47	-1567.56	-1799.11	-453.25	27
50	0.20	-1125.47	343.12	-231.05	-1565.98	-1797.96	-452.98	27
60	0.19	-1121.72	343.78	-228.38	-1556.88	-1795.52	-447.91	27
70	0.16	-1115.41	346.43	-228.21	-1553.90	-1794.39	-436.43	27
80	0.16	-1114.66	346.52	-228.11	-1553.77	-1793.82	-435.50	27
90	0.16	-1114.13	346.58	-227.99	-1553.65	-1793.42	-434.84	27
100	0.13	-1108.44	348.56	-219.81	-1528.95	-1791.61	-425.28	27
150	0.04	-1084.37	357.37	-211.42	-1515.31	-1784.80	-383.94	27
200	0.06	-1108.22	343.92	-129.18	-1505.17	-1782.29	-434.15	24
250	0.01	-1093.75	338.21	-129.66	-1519.01	-1756.64	-430.87	23
300	0.00	-1040.47	386.64	-62.86	-1523.56	-1798.26	-282.67	14
350	0.08	-1094.20	249.99	-758.52	-1403.27	-1584.18	-604.22	9
400	0.29	-1145.65	281.69	-716.82	-1406.87	-1697.76	-593.54	6
450	0.00	-1092.33	244.94	-689.67	-1341.78	-1572.40	-612.26	5
500	0.05	-1156.23	135.40	-1057.71	-1353.03	-1421.61	-890.84	4
550	1.00	-1050.55	29.42	-1029.75	-1071.36	-1108.22	-992.89	2
600	1.00	-956.81	76.18	-902.95	-1010.68	-1106.11	-807.51	2
650	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1
700	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1

Wt_Threshold (lbs)	r²	mean diff (lbs)	stdev diff (lbs)	max diff (lbs)	min diff (lbs)	lower limit (lbs)	upper limit (lbs)	Sample Size
	Scale 1 + 2 + 3							
1	0.08	-943.58	350.41	-49.42	-1424.06	-1630.38	-256.78	27
5	0.08	-941.59	350.92	-49.01	-1423.87	-1629.39	-253.79	27
10	0.08	-941.03	350.89	-48.34	-1423.69	-1628.76	-253.29	27
20	0.08	-940.02	351.08	-45.13	-1423.34	-1628.13	-251.92	27
30	0.08	-939.29	351.07	-44.61	-1423.01	-1627.37	-251.21	27
40	0.08	-938.49	350.96	-44.23	-1422.70	-1626.36	-250.63	27
50	0.08	-935.64	349.54	-43.75	-1422.55	-1620.73	-250.56	27
60	0.08	-934.91	349.49	-43.40	-1422.27	-1619.89	-249.92	27
70	0.08	-934.39	349.43	-42.95	-1422.01	-1619.26	-249.52	27
80	0.08	-933.80	349.27	-42.41	-1421.76	-1618.36	-249.24	27
90	0.09	-932.95	348.98	-41.58	-1421.54	-1616.94	-248.95	27
100	0.08	-931.80	349.79	-33.54	-1421.33	-1617.37	-246.22	27
150	0.07	-920.83	355.50	-11.38	-1420.20	-1617.60	-224.05	27
200	0.03	-894.57	362.57	-3.01	-1419.77	-1605.20	-183.94	27
250	0.04	-883.90	359.75	-2.43	-1348.09	-1589.00	-178.81	27
300	0.02	-866.36	365.51	22.37	-1348.22	-1582.75	-149.96	27
350	0.00	-842.06	384.77	57.78	-1348.56	-1596.21	-87.92	27
400	0.00	-807.95	392.64	61.10	-1355.60	-1577.51	-38.40	27
450	0.00	-793.86	395.01	47.52	-1362.26	-1568.06	-19.67	27
500	0.09	-757.47	392.28	291.19	-1362.89	-1526.32	11.39	26
550	0.16	-759.20	417.17	293.04	-1363.63	-1576.84	58.45	24
600	0.11	-733.52	417.14	294.24	-1364.48	-1551.10	84.05	24
650	0.09	-737.54	420.87	294.49	-1365.77	-1562.44	87.36	23
700	0.03	-683.49	389.82	293.89	-1367.99	-1447.52	80.54	23

APPENDIX O

FFT TABLES 3 – SCALE DAIRY CATTLE

	Source	r2	mean diff	stdev diff	upper limit	lower limit	sample size
DC	Scale 1 + 2 + 3	0.04	-1069.12	273.46	-533.14	-1605.09	27
	Scale 1 + 2	0.02	-1125.16	272.46	-591.15	-1659.18	27
	Scale 1 + 3	0.01	-1164.51	275.98	-623.60	-1705.41	27
	Scale 2 + 3	0.02	-1150.80	272.41	-616.88	-1684.72	27
	Scale 1	0.02	-1214.55	267.97	-689.34	-1739.76	27
	Scale 2	0.04	-1202.16	264.80	-683.17	-1721.16	27
	Scale 3	0.02	-1238.53	267.07	-715.09	-1761.98	27
DC + 1	Scale 1 + 2 + 3	0.02	-1066.77	273.90	-529.93	-1603.61	27
	Scale 1 + 2	0.00	-1086.79	284.46	-529.27	-1644.32	27
	Scale 1 + 3	0.04	-1123.50	265.36	-603.39	-1643.60	27
	Scale 2 + 3	0.00	-1176.79	275.14	-637.52	-1716.06	27
	Scale 1	0.04	-1223.85	265.21	-704.04	-1743.65	27
	Scale 2	0.01	-1250.55	268.87	-723.56	-1777.53	27
	Scale 3	0.05	-1246.83	263.75	-729.89	-1763.76	27
Max Amplitude	Scale 1 + 2 + 3	0.06	-1034.98	265.32	-514.97	-1554.99	27
	Scale 1 + 2	0.02	-1078.52	277.24	-535.13	-1621.91	27
	Scale 1 + 3	0.03	-1118.87	269.47	-590.72	-1647.01	27
	Scale 2 + 3	0.02	-1141.34	270.96	-610.27	-1672.42	27
	Scale 1	0.02	-1214.55	267.97	-689.34	-1739.76	27
	Scale 2	0.04	-1202.16	264.80	-683.17	-1721.16	27
	Scale 3	0.02	-1238.53	267.07	-715.09	-1761.98	27

APPENDIX P

RMS 3 – SCALE DAIRY CATTLE

Wt_Threshold (lbs)	r^2	mean diff (lbs)	stdev diff (lbs)	max diff (lbs)	min diff (lbs)	lower limit (lbs)	upper limit (lbs)	Sample Size
					Scale 1			
1	0.06	-912.69	354.41	43.56	-1465.24	-1607.32	-218.07	27
5	0.14	-899.02	341.90	49.89	-1329.69	-1569.13	-228.91	27
10	0.14	-897.57	341.77	50.41	-1326.25	-1567.42	-227.72	27
					Scale 2			
1	0.27	-1031.10	325.71	-167.85	-1575.55	-1669.48	-392.73	27
5	0.27	-1030.43	325.58	-167.58	-1575.40	-1668.56	-392.31	27
10	0.27	-1030.00	325.48	-167.40	-1575.24	-1667.93	-392.07	27
					Scale 3			
1	0.08	-1027.48	311.15	-183.73	-1471.13	-1637.33	-417.63	23
5	0.08	-1018.05	310.97	-183.16	-1471.06	-1627.54	-408.56	23
10	0.08	-1017.31	311.09	-182.28	-1470.99	-1627.03	-407.59	23
					Scale 1 + 2			
1	0.22	-1053.89	336.54	-160.01	-1542.65	-1713.50	-394.29	27
5	0.22	-1053.31	336.49	-159.68	-1542.30	-1712.81	-393.81	27
10	0.22	-1052.47	336.29	-159.26	-1541.95	-1711.59	-393.36	27
					Scale 2 + 3			
1	0.22	-1112.22	343.07	-241.98	-1563.81	-1784.62	-439.83	27
5	0.22	-1111.95	343.04	-241.82	-1563.81	-1784.29	-439.62	27
10	0.22	-1111.71	343.05	-241.25	-1563.81	-1784.08	-439.34	27
					Scale 1 + 3			
1	0.26	-1103.16	338.46	-220.25	-1544.38	-1766.53	-439.79	27
5	0.26	-1102.82	338.45	-219.42	-1544.11	-1766.17	-439.47	27
10	0.26	-1102.28	338.25	-219.25	-1543.94	-1765.23	-439.32	27
					Scale 1 + 2 + 3			
1	0.10	-864.65	346.80	20.94	-1341.86	-1544.37	-184.94	27
5	0.10	-863.48	347.00	21.20	-1341.73	-1543.60	-183.36	27
10	0.10	-863.11	346.98	21.62	-1341.59	-1543.17	-183.05	27

VITA

JORDAN DAVID FISCHER

Candidate for the Degree of

MASTER OF SCIENCE

Thesis: DEVELOPMENT OF A MULTI-SCALE WALKOVER PLATFORM FOR PRECISION LIVESTOCK MANAGEMENT

Major Field: BIOSYSTEMS ENGINEERING

Biographical:

Education:

Completed the requirements for the Masters of Science in Biosystems Engineering at Oklahoma State University, Stillwater, Oklahoma in May, 2019.

Completed the requirements for the Bachelor of Science in Biochemistry and Molecular Biology at Oklahoma State University, Stillwater, Oklahoma in May, 2016.

Experience:

Graduate Research Assistant, Oklahoma State University, 2016 – 2019

Professional Memberships:

American Society of Agricultural and Biological Engineers, 2017-2019