Pre-slaughter assessment and selection in commercial beef cattle in relation to final carcase classification

---

H.R. Scott-Browne

A thesis submitted for the degree of Doctor of Philosophy

Department of Agriculture (Writtle University College)

University of Essex

September 2018

ABSTRACT

The way we assess readiness for slaughter in beef cattle has not progressed in the past 200 years, with subjective visual and manual assessments of cattle still the primary mechanisms used to determine peak condition, resulting in less than half of all cattle carcases meeting a UK premium classification. Current losses to the UK Beef industry are estimated at approximately £12.5 million per year through the sending of over-fat and poorly conformed cattle to the abattoir. With global population rapidly increasing, there is a fundamental need to provide more food efficiently and effectively from the resources we have. Therefore, successfully reducing wastage and improving carcase quality across the UK beef industry through accurate assessment and selection of beef cattle for slaughter is an important step forwards towards a sustainable future for beef production. The EUROP system of bovine carcase classification dictates which carcases are most desired for the current market, with those failing to meet market specification subject to a penalty. The aim of this research project was therefore to provide farmers with an objective tool using a binary logistic regression model, to combine fat and morphometric measurements taken from live cattle, in order to help predict which cattle are most likely to achieve a desired carcase classification and therefore most suitable for slaughter. Through the use of a series of binary logistic regression models, it was discovered that out of 15 measurements taken from cattle, a combination of pelvis height, pelvis width, 10^{th} and 12^{th} rib fat point readings and the P8 fat point reading were best able to predict the likelihood of cattle meeting a UK premium carcase classification. In a later study, when breed was factored into the model on a larger, more commercial scale, this reduced the number of measurements required to just the pelvis width and 12^{th} rib fat point reading, subsequently increasing the practicality to apply this research on-farm.

CONTENTS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF PLATES

LIST OF TABLES

LIST OF APPENDICES

ACKNOWLEDGEMENTS

From the moment I started this doctorate, I have thought endlessly about how I would write this section, and who should be included. Over the seven years, this list has just grown longer and longer! I can safely say that this thesis has been, and will probably be, without doubt the most testing and difficult thing I have ever accomplished in my life so far! I have lost count of the amount of times I have wanted to quit, give up and throw it all away and I really would have, if it weren't for a few truly amazing people refusing to let me give up!

So firstly, I would like thank three people who have been the best friends and stuck with me throughout it all: Jessica Rose, Emma Reggione and Hannah Nutter. This really wouldn't have been possible without any of you, be it helping with data collection years ago (still never letting you forget the cow pat incident, Hannah!) or just being at the end of the phone refusing to let me give in and quit – for the eleventh time that day! Secondly I have to give thanks to Barbara Feldmanis, who has always helped me to believe in myself and that I could achieve anything I put my mind to, regardless of what life threw in the way! You've taught me so much over the years…and I am sure the endless rearrangement of shelving units and dog beds has finally come in useful during the last rearrangement of my chapters! Next I thank Ade and Fi Barwick (and dogs!) You have always been like a family to me, allowing me to escape to the wilds of Yorkshire when things got too much, yet always being there to offer advice and support while going out of your way to help me. The final study in this project really could not have happened without your input. So a massive thanks goes to you.

Further thanks go to a fantastic group of people I met in a field (or several fields!) way back in June 2015, who have gone on to become my big, psychedelic, awesome extended family! I would list you all but I'd need at least another 12 pages! There's never any judgement or questions asked, you've always just been there to accept me when going got tough, given me some great new music to write to and allowed me that occasional essential break from the academic world, whilst ALWAYS giving me words of support and encouragement online. So I thank you all so very much. I love you all! See you in a field soon to celebrate! Following on from above I have to thank someone in particular: Roz Bruce. A true inspiration/partner in crime/chief motivator/counsellor/soul mate/fellow academic/great friend. You get it and more importantly - you're always there when I need a hike ;)

Next I have to thank everyone at Writtle University College; firstly for giving me the opportunity to undertake this research through a "no fees PhD" scheme. I then need to thank all of the staff at Sturgeon's Farm – I could not have done it without your assistance; the Science Department Lab Technicians – (in particular, Laura Whittaker for being a tireless counsellor and great friend for the past 7 years - thank you for putting up with me!); fellow colleagues such as Caroline Flanagan – remember that day I came to your office in a right state, saying I was quitting, and you said you'd drag me through this by my hair if you had to….well, here we are, and my hair is still intact (just!); Nicola Blackie – it's your fault I love cows so much, if it weren't for your supervision and support during my dissertation all those years ago, I wouldn't be here now!; Tracey Coop – I honestly don't know where to start! You've seen me at my lowest, helped me when I was at my worst and will no doubt be there to help me have a damn good celebration! You're a proper legend!

Most importantly I have to thank my supervisors; Jon Amory and Nik Selemetas. You both stepped in last minute to help see me through these final few years, words cannot say how much I appreciate that. I think I owe you several boxes of tissues! Your never-ending patience, support and determination to see me through the ups and downs of this academic adventure has been amazing. I thank you so much for never giving up on me!

I now have to thank Steve Powdrill from AHDB Beef and Lamb for helping me fund and distribute my questionnaire study all those years ago. It has formed the basis for my whole thesis so I couldn't have done it without you. Further thanks goes to Gena Douglas and the staff at Marishes Farm, Moulton, North Yorkshire. You are literal lifesavers! The final study would not have been possible without your help. So a massive thank you.

To three special teachers from my childhood – it's your love and passion for science, education and teaching that initially got this ball rolling. Technically, this whole thing is your fault! You all inspired me in different ways, and for that I am grateful. So thank you to Mandy Watts, Judith Marshall and Hannah Davey-Smith.

Finally, my last thanks goes to my family. To my mum and dad – you may not have always known what I'm doing (something to do with cows?!), you may not know why it's taken me so long to do it (you might when you hold this!), but here it is! At last! Thank you for your support and encouragement over the years, and for ensuring I never gave up no matter how hard it got! To my sisters Sharley and Sammy. Sharley, you're a true inspiration. Seeing you make and live your own life in Sweden, despite the odds and difficulties inspired me never to give up on my dreams. Thank you. And Sammy, I believe I started this mission when you were only 7, so I've been doing this almost half your life…which probably means in your mind I'm always going to be your crazy, cow-obsessed sister….but I'm ok with that! Thanks for your support and fun when I needed a break away from studying! And FINALLY thanks to Oreo for adding in made-up cat words halfway through Chapter 6…it only took me several months to realise! Thank goodness for proof-reading!

Ok, I think I'm done! To anyone I may have accidentally forgotten to mention and to everyone that has ever said a kind word of support or encouragement, or who has given me a right kick up the butt when I needed it – I thank you!

Dedicated to Margaret Dulcie Scott-Browne

5th August 1930 – 4th July 2017

Your passion and love for life, nature and the outdoors will live on in this forever.

I hope I've done you proud.

R.I.P

CHAPTER 1. INTRODUCTION TO THE UK BEEF INDUSTRY

1.1. INTRODUCTION

Across the United Kingdom, current live-animal assessment and selection methods in commercial beef cattle are failing to achieve desired carcase classification at slaughter. This is resulting in significant financial costs and wastage within the UK beef industry simply through the sending of cattle with poor muscular development; cattle which are overly-fat; lean cattle or under-finished cattle to slaughter. Therefore the main focus of this research was to find out whether a more objective method of live-animal assessment is plausible and can be used to help reduce wastage as well as expenses and penalties incurred to beef farmers. This would be achieved by adapting and combining morphometric measurements and ultrasonic fat readings described in previous scientific studies, with the potential to construct a tool which would allow farmers to objectively assess and select live cattle for slaughter through linking these measurements in with subsequent carcase classification. So to summarise, the aim of this research was to find a selection of easily accessible measurements that farmers can undertake on-farm which will allow for them to objectively determine whether or not an animal is suitable for slaughter.

To begin with, the first chapter gives a brief introduction and background to the UK beef industry and the carcase classification system as it currently stands, alongside further reasons and justifications for undertaking this research, as well as discussing why current live-animal assessment and selection methods are failing to achieve high levels of desirable carcase classification.

1.2. BRIEF BACKGROUND

In 2015 in the UK, 1.92 million prime cattle were slaughtered, producing 684,000 tonnes of meat (Agriculture and Horticulture Development Board (AHDB), 2016a). Of these animals that were slaughtered, less than 20% met desired R4L carcase classification and furthermore, less than half of all of the cattle carcases attaining the desirable R conformation (AHDB, 2016a). This is a continuing trend which has followed on from the previous year. In 2014, the total percentage of cattle meeting UK premium classes (based on the standard EUROP carcase classification grid, these classes consist of E3, E4L, U+3, U+4L, -U3, -U4L, R3, R4L) was less than half of all prime cattle sent to the abattoir (a total of 48.9%) (AHDB, 2016a). This failure to meet quality carcase classifications means that significant financial losses to the UK beef industry are seen as farmers are penalised and penalties are administered due to the sending of unsuitable animals to slaughter. When looking at the prices allocated to different carcase classes, according to EBLEX (2014), in Southern England in January 2013 the average price of a steer carcase of R4L standard was 372 pence per kilogram, and that of a heifer was 372.5 p per kg. In contrast to this an animal falling outside of UK premium specification, for example a steer carcase of the grade –O4L, only reaches a price of 346.6 p per kilogram. This may not seem like a significant monetary difference at first, but once the whole animal is taken into account, there is a substantial loss seen in the cattle that didn't make the grade. For example, in December 2016 the average steer carcase weighed 372.4kg (AHDB, 2017) with the average price per kilogram for an animal graded as R4L being 365.3 pence per kilogram (AHDB, 2018). This makes the average R4L graded carcase worth approximately £1,360.38. In comparison, a steer graded as O+2 in the same month averaged a price of 337.2 pence per kilogram (AHDB, 2018). This works out at a carcase price of £1255.74. This is a loss to the farmer of £104.64 through the sending of an animal with poorer conformation and fat class to slaughter and highlights the financial loss seen to the industry on a daily basis. This significant decrease in price due to a carcase not meeting desired UK specification therefore needs to be addressed and the reasons why cattle are failing to meet specification analysed in order for potential solutions to this problem to be constructed. In order to achieve this, a generalised understanding of the terminology used within the European beef sector first needs to be established to allow for clarity when discussing the UK carcase classification system.

1.2.1. Terminology used in the beef industry

Over the many years that classification systems have been utilised within the beef industry, there has been much confusion over the terminology used to describe carcase assessment in terms of classification, conformation and grading (AHDB, 2008; Polkinghorne and Thompson, 2010). It was also identified that a major concern within the beef production sector was the inability to objectively determine what was meant by "quality" when describing a carcase (Preston and Willis, 1974), thus meaning that a "good quality" carcase in the view of a producer may not necessarily be a good quality carcase in the opinion of a processor or retailer (Boukha et al., 2011). This confusion within the industry in regards to the different terms used to describe carcase assessment has often resulted in misunderstandings between the beef producer and the market (Green et al., 1999), causing a lack of clarity and trust between abattoirs, producers and retailers (Polkinghorne and Thompson, 2010). It is understood that even today, terms such as grading and classifying are often used inter-changeably to describe the same process of carcase assessment, causing confusion throughout the industry (Department: Agriculture, Environmental Affairs and Rural Development (DAEA), 2005; AHDB, 2008; Polkinghorne and Thompson, 2010).

In 1964, Wardrop defined grading as:

“A process which attempts to divide a heterogeneous group of material into sub-groups, within each of which the material has similar characteristics”

This concurs with Pierce’s prior description of grading in 1959 which stated that grading was simply the segmenting of the commodity into groups which share similar characteristics and that this grading should be based on what is important to the market at the time. Subsequently, it was therefore decided that grading alone should refer to the different monetary values placed on carcases depending on market demands and trader requirements (AHDB, 2008; Polkinghorne and Thompson, 2010) whereas the term “classification” refers to the category given to a carcase due to the conformation and fat level assessments (Rural Payments Agency (RPA), 2011a). Therefore, for the purpose of this thesis, the term “grading” shall apply when monetary value is discussed in reference to carcase classification, whereas “classifying” is simply the assigning of a carcase to a particular category within the EUROP carcase classification grid.

Other words which are often used inter-changeably within the beef industry are the terms “carcase” and “carcass”. The terms differ in that some say “carcass” refers to the body of a dead animal prior to the dressing process, whereas “carcase” describes the body of an animal after removal of certain anatomical features and/or dressing for human consumption has occurred (Blood et al., 2007). However, in many scientific articles, alongside magazine publications, it has been seen that both of these terms are often used interchangeably, with the Meat and Livestock Commission in their glossary again using the terms interchangeably (EBLEX 2012a). This could add to the confusion often seen in regards to terminology used within the beef industry and is a continuous on-going debate. For the purposes of this research, “carcase” shall refer to the body of an animal after dressing and “carcass” shall refer to the entire dead animal. It is through clarification of the terminology used in the industry over the years that a greater understanding of the development and utilisation of the current beef carcase classification system can be achieved.

1.2.2. What is carcase classification and grading?

Classification itself refers to the assignment of a carcase into a particular group, based on the EUROP carcase classification grid; whereas the term "grading" is used in reference to the monetary value placed on the groups within the classification grid. Bovine carcase classification can therefore be defined as the overall assessment of a carcase to ascertain its usefulness and value within the beef industry.

This definition arises from that given by Fisher and Heal (2001):

"The assessment of a carcase for its suitability and value for a particular use within the industry"

Alongside this, Polkinghorne and Thompson (2010) further described carcase classification as:

"A set of descriptive terms describing features of the carcass that are useful...in the trading of the carcass"

Drawing from these statements, it can be determined that carcase classification, grading and eventual trade and sale of the meat are inseparable from one another, thus demonstrating the underlying importance of sending properly conformed and developed animals to slaughter.

Grading of beef carcases is therefore essential within both the UK and European beef industries in order to ensure that producers receive fair, standardised payments for their animals, allowing for transparency in markets across the entire European beef industry

(Drennan et al., 2008; RPA, 2011b). With prices varying between the different grades assigned to carcases, producers have a greater incentive to try and produce cattle with carcases that are required by the specific market (Drennan et al., 2008). Globally, carcase grading is based primarily on factors such as identification and sex of the animal, carcase weight, dressing specification, conformation, fat and meat quality assessment (Polkinghorne and Thompson, 2010). However, within the UK and other European countries, the EUROP system of carcase grading is fundamentally based on subjective, visual assessments of conformation and fat level (RPA, 2011a; Craigie et al., 2012), with Kempster et al. (1982) finding that visual conformation assessments related well to lean to bone ratios and muscle thickness, however they were of little value as a predictor of carcase composition. Nowadays these visual assessments and subsequent grading of carcases are now being taken over by video image analysis within the larger abattoirs (Rius-Vilarrasa et al., 2009).

The assessment and selection of the factors involved in carcase grading varies between different countries across the world, with individual countries having their own versions of grading systems (Kirton, 1989), but all of which aim to allow for clarity throughout the entire supply chain (Fisher and Heal, 2001; Rius-Vilarrasa et al., 2009). However, it is within the European Union alone that the generalised EUROP system is currently in place (Verbeke et al., 2010), with only slight differences in grading systems seen between the member states.

Bovine carcase classification systems work by assessing and interpreting many different factors which make up the final classification score assigned to a carcase. Within the EU, the criteria for carcase classification is primarily dependent on assessments of conformation (overall shape) and fat class (level and density of fat) (Department for Agriculture, Food and the Marine (DAFM), 2013), with these assessments alone being the tool used within the meat industry to determine payment given to farmers (Kongsro et al., 2009). It is stated in the European Commission Regulation (EEC) No 344/91 Article 2 (2) that if an abattoir slaughters more than 75 cattle per week, the classification of the carcases of these animals is compulsory (RPA, 2012a; DAFM), 2013). However, in order to work effectively, classification systems do depend on accurate and standardised interpretations of what is meant by conformation and fat class, as without having a thorough understanding of what constitutes these two vital components, standardisation of payments given to farmers for their beef carcases across the UK would not be possible.

1.2.3. Carcase conformation and fat class

Carcase conformation was described by the European Council Regulation (1208/81) as the development of the profile of the carcase, particularly in the areas of the hindquarters, back and shoulders (Hybu Cig Cymru (HCC), 2007; AHDB, 2008) and can be assessed in the live animal as well as the carcase (EBLEX, 2011). Conformation does not give a description of the fat level of the carcase and merely describes the overall shape, primarily done through visual assessments of the live animal (EBLEX, 2011). Conformation is not only useful in terms of describing the shape of a carcase (see table 1.1 below), but also plays an important part in the price negotiations between producers and the beef market (Diez et al., 2006), with the more desirably conformed animals reaching higher prices.

In the EU, the scale for conformation based on the EUROP system of classification ranges from E (excellent) to P (poor) (Diez et al., 2006) with an extra grade (S) for those extreme double-muscled animals which exceed the EUROP scale (Eriksson et al., 2003; AHDB, 2008; Yeomans, 2009; Conroy et al., 2010), although this is rarely (if ever) used within the UK and is only authorised for use in some member states (DAFM, 2013). Table 1.1 below demonstrates the visual assessments of a live animal, based on the EUROP carcase classification system, which are used when determining whether cattle are in prime slaughter condition. This classification of conformation forms half of the carcase classification system used in the EU, with the final part of the classifying being described through assessments of fat level.

Table 1.1. EU Conformation Classification Scale

Conformation Class	Description of Animal/Carcase
S	Superior (rarely used in UK and usually reserved for double-muscled animals). Extremely convex profiles. Tends to be animals of double-muscled form.
E	Excellent. Exceptionally muscled form. Very convex profiles.
U (+/-)	Very Good. Good muscular development. Convex profiles.
R	Good. Good muscle development. Straight profiles.
O (+/-)	Fair. Average muscle development. Slightly concave profiles.
P (+/-)	Poor. Poor muscle development. Very concave profiles.

Source: Adapted from the Rural Payments Agency (RPA) (2011c).

The second half of the description of cattle carcases is fat class. This describes the extent of fat coverage seen either on the live animal or carcase by an assessor, with particular attention paid to the hindquarters, spine and rib areas (EBLEX, 2011; RPA, 2011a). Fat is the most variable of all bovine tissues (Jones et al., 1978) and therefore the hardest to predict in terms of pre-slaughter assessment of cattle, although it has been found that breed and slaughter weight have a direct impact on the fat content of a carcase (Insausti et al., 2005).

Assessment of fat cover forms the second half of the EU classification system, with the classification scores given ranging from 1 (a low level of fat tissue) to 5 (a high level of fat tissue), with classes 4 and 5 being split into leaner (L) and fatter (H) bands for a more detailed description of the carcase (Diez et al., 2006; Conroy et al., 2010; RPA, 2011a). Fat levels 3 and 4L are the most desirable within the UK beef industry as these are best suited to fit general market specification. The table below demonstrates the difference in fat class in relation to each other:

Table 1.2. EU Fat Level Classification Scale

Fat class	**Description of animal/carcase**
1	Low fat level
2	Slight fat level
3	Average fat level
4 (L/H)	High fat level
5 (L/H)	Very high fat level

Source: Adapted from the Meat and Livestock Commercial Services Ltd. (MLCSL) (2009).

Fat level, like conformation, has a significant impact on the monetary value placed on the carcase, with overweight, fat carcases being heavily penalised, resulting in a loss of value (EBLEX, 2011). It is through both desirable fat class and conformation grading that the carcase reaches an optimum or prime category on the EUROP grid, thus being the most beneficial in terms of optimum pay-out to the producer and in value to the meat industry.

1.2.4. The EUROP system of carcase classification

The EUROP system of carcase classification combines the aforementioned conformation assessment and fat class to give a final, standardised description of a bovine carcase. Drennan et al. (2008) stated that there were strong relationships between the specific EUROP category assigned to a carcase and the proportion of meat produced, thus making it a reliable method of paying farmers according to carcase quality. When describing a carcase according to the EUROP system, it is the conformation assessment which is described first, followed by the fat class (AHDB, 2008). For example, a carcase with the conformation “R” and a fat class of 4H would be described as “R4H”. When both the conformation assessment and fat class are combined in a tabular format the modern-day, standard EUROP system is presented, as shown in figure 1.1 below:

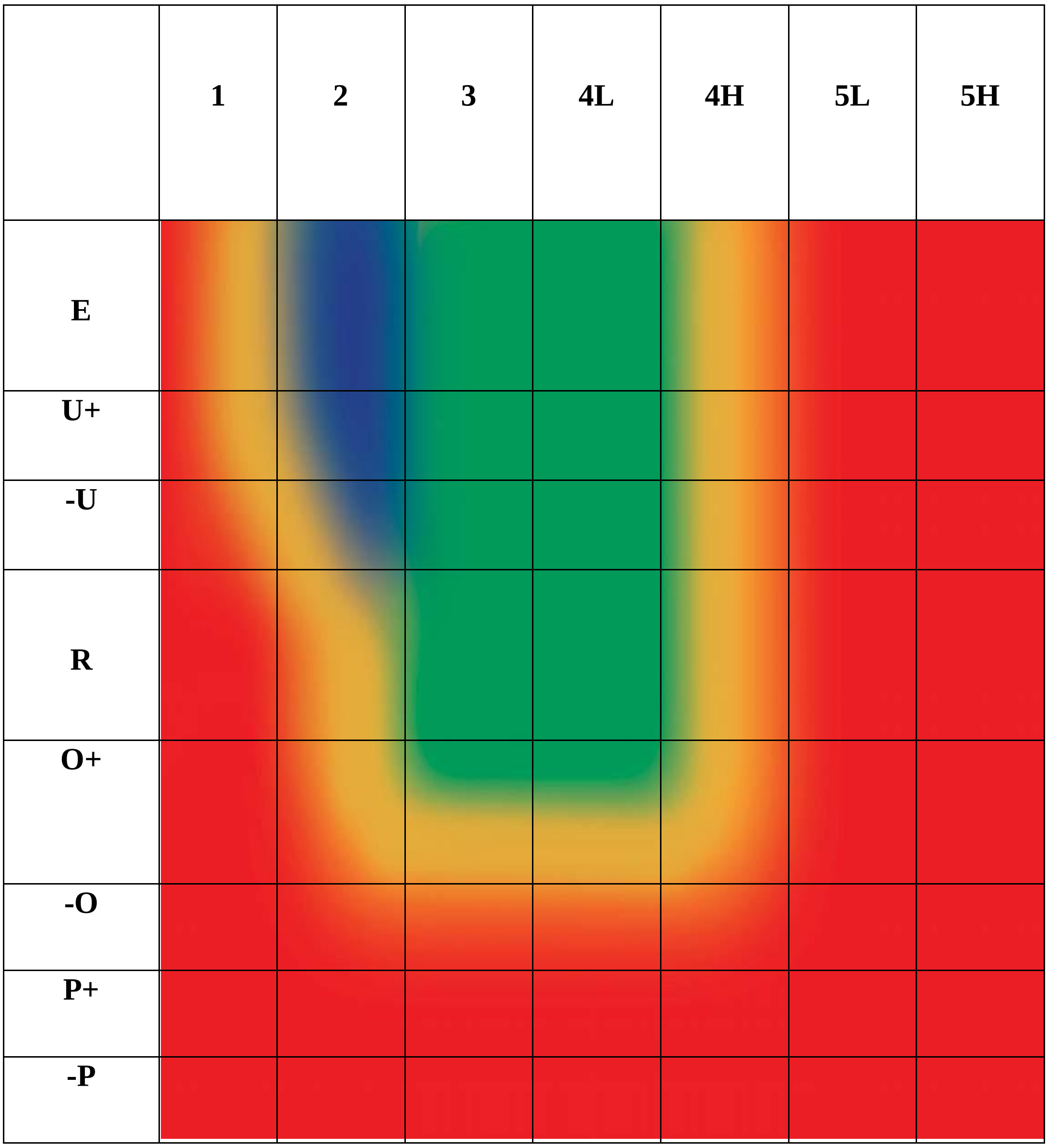


Figure 1.1. The Current EUROP System of Bovine Carcase Classification
Source: Adapted from the English Beef and Lamb Executive (EBLEX) (2007)

Each band of colour on the figure above represents a different market specification. The classifications coloured red are where there is little or no demand for that specific type of bovine carcase, whereas the green areas represent high UK demand, particularly for supermarket specification, and the best returns with premium prices (EBLEX, 2007). For the purposes of this study, any carcases falling within the green or blue areas shall be referred to as “UK Premium.” The blue areas on the figure above indicate the specific classifications that are either best suited for export to other markets in the EU, or for high-end UK butchers. It is therefore important within the beef industry to try and get as many bovine carcases to meet the desired green (and sometimes yellow or blue) classifications due to the higher demand and better premiums received for such produce.

Although the EUROP beef classification scheme is adopted across member states of the European Union, there is variance in the division of each conformation and fat class seen between member states. Current legislation allows for up to 3 subdivisions to be permitted for each class (DAFM, 2013). In the United Kingdom, classes U, O, and P for conformation and classes 4 and 5 for fat class are subdivided into 2 bands in order to better describe the carcase. However in Ireland, the class P is subdivided 3 times to describe decreasing conformation (P+, P, P-). Other differences can be seen in Italy and Germany (which have no subdivisions at all) and also in the Netherlands, Denmark and Sweden, which divide all conformation classes into 3 subdivisions (DAFM, 2013). Furthermore, a 15-point EUROP carcase classification grid is now in use across the larger abattoirs within the UK. This grid splits each category into the full 3 subdivisions allowed under the carcase classification legislation to allow for greater description when classifying a bovine carcase and is particularly used when video image analysis techniques are used for carcase classification (Anglo Beef Producers (ABP), 2017).

1.2.5. Current live-animal selection methods

Live animals are often assessed for final carcase composition according to both visual assessments and manual handling of body shape (EBLEX, 2011) in order to estimate carcass composition and the distribution of muscle tissue; factors closely linked to the final value of a meat carcase (Berg and Walters, 1983). Proficiency in the area of live animal assessment allows producers to improve profitability through improving the compliance rates of their animals meeting desired market specification, although these assessment skills can only be developed through time and practice or after specific training (Littler, 2007). When helping to establish peak slaughter condition in cattle, EBLEX have devised two methods (recommended to be used in conjunction with one another) to attempt to achieve this. These methods, though deemed subjective by some researchers (McKiernan and Sundstrom, 2006), are the only current recommended ways of assessing and selecting live animals prior to slaughter, although some farms still rely heavily on weight recording in conjunction with these methods when selecting animals for slaughter (Scott-Browne and Cooke, 2014).

In beef production, carcase weight is one of the most important pieces of information used to calculate the overall price of the carcase (Alonso et al., 2013) and therefore the live weight of an animal is important when selecting animals for slaughter (EBLEX, 2012a). In the UK, optimum live-weight for slaughter can vary between abattoirs, but with the majority of abattoirs offering the best premiums for a medium animal of approximately 500-650 kg (Hybu Cig Cymru (HCC), 2014a). The recording of weight is an objective means of pre-slaughter assessment in beef cattle; as well as helping to monitor the growth rates and was used as far back as 1887 to determine the price an animal should be sold at (Board of Agriculture, 1901; National Archives, 2011a). Littler (2007) stated that the best way to measure the weight of a live animal in order to meet specific market specifications is through the use of electronic scales so that growth and weight-gain performance can be monitored.

Carcase weight reflects growth rates throughout an animal's lifetime (Campion et al., 2009) so it is therefore of great importance to the beef producer to monitor weight gain throughout the lives of their cattle in order to ensure that they meet desired carcase weight at slaughter, resulting in a premium pay-out (providing the carcase is adequate in terms of conformation and fat level). However, it is not recommended to send animals to the abattoir based purely on weight alone as overly fat animals inevitably weigh more and so be sent earlier, and yet result in penalties through the need for excessive trimming of the extra fat (RPA, 2011a). This is why other methods of live-animal assessment (used in conjunction with weight recording) are vital in helping to ensure cattle achieve optimum classification at slaughter.

The first of the recommended methods of live animal assessment is the basic visual assessment of the animal. Visual assessments focus mainly on assessing the conformation and overall body shape of a beef animal through observations of key indicator sites. The key indicator sites described by EBLEX (2007) are the round and rump region, the loin and back area, the shoulders and the fullness of the brisket. It is stated that cattle of good conformation have a convex shape, wide between the legs and are thickly fleshed with a trim brisket (EBLEX, 2007). However, McKiernan and Sundstrom (2006) stated that this visual appraisal of cattle for both conformation and fat level assessments (especially when used to determine readiness for slaughter) is notoriously subjective and less accurate than the physical manual handling techniques.

The second recommended method of live animal assessment is the actual handling of specific key indicator sites, known as manual handling. On-farm manual handling techniques are used mainly for assessing the fat level of a beef animal and handling occurs where the main fat deposits are laid and can be felt with the fingertips (Littler, 2007; McKiernan and Sundstrom, 2006). According to EBLEX (2007), the specific areas to handle on a beef animal when assessing fat level are the pin bones and tail head, the round, the loin and transverse processes, over the ribs and the ridge of the shoulder blade. However, McKiernan and Sundstrom (2006) stated that the best areas to manually assess fat depth are those not associated with high muscle content (such as the round), to allow for differentiation between fat and muscle tissues, with their greater focus of the manual handling techniques being on the rib area, loin and tail head, particularly in younger animals. Fat assessment through use of manual handling techniques is a skill learnt through practice and therefore continuous practice is essential in order to maintain accuracy of assessments using this method (McKiernan and Sundstrom, 2006). This continuous practice is not necessarily possible on farms sending cattle to the abattoir on a less frequent basis and thus could be a source of potential error and lead to failure in assessing and sending prime cattle to slaughter. EBLEX have noted this, and have constructed several tools to aid in live animal assessment in order to improve post-slaughter classification. These include abattoir open days as well as programmes which use computer simulation models which aim to help the beef producer in ensuring that they can detect when their animals meet desired market specification.

1.2.6. Tools to aid live-animal assessment

Free open abattoir days, known as Live-to-Dead days, are where farmers follow cattle through the entire slaughter process and are shown specific handling and assessment points in the live animal, thus honing and improving their live-animal selection skills. They learn that while the weight of the animal is important when selecting for slaughter, it is vital that animals of the right conformation and fat score are sent to the abattoir (EBLEX, 2012a), in order to ensure greatest financial outcome and best possible carcase classification. The farmers then go on to view the same animals they assessed and handled live as carcases later on that day, with the assistance of experienced personnel from both EBLEX and the Meat and Livestock Commission (EBLEX, 2012a; Livestock Northwest, 2013). In Wales, these days are known as the Cattle and Sheep Selection for Slaughter Training Programmes but again, emphasis is placed on the importance of visually and manually assessing animals at specific regions prior to slaughter in order to help identify when an animal is in prime condition (HCC, 2014b). Between the months of April 2012 and March 2013 there was a 96% satisfaction rating among those farmers who chose to attend a live-to-dead day (EBLEX, 2013a), thus demonstrating the positive impact attendance to one of these days has on farmer confidence in beef animal selection for slaughter.

The EBLEX Better Returns Programme (BRP) is a knowledge transfer programme which incorporates both computer simulation programmes and online resources alongside booklets and manuals to aid farmers in live animal selection, assessment and carcase classification of both sheep and beef carcases. The booklets contain colour photographs of live cattle at different selection levels and also demonstrate different handling points for assessing fatness and conformation. Simulation models allow farmers to see cattle at different selection levels from all angles, giving them a visual representation of what to look out for in their own animals when they reach a desirable shape. The BRP focuses on aiding farmers within the 5 main management areas within the beef and sheep industries, these being breeding, selection for slaughter, health and fertility, nutrition and forage and systems and costing (EBLEX, 2013b). Over 250 events were held under the BRP relating to stock selection and management practices were held between April 2012 and March 2013, with 5,400 beef and lamb producers attending (EBLEX, 2013b). In 2013 there were 27,000 members signed up to the BRP, and an 80% satisfaction rating with the materials (such as technical manuals) received (EBLEX, 2013a).

However, even with the use of these current live-animal assessment aids, the beef industry is still suffering significant financial losses in terms of sending unfit animals to slaughter. This therefore highlights the importance of developing and utilising alternative methods of live-animal assessment which have a more objective basis than just visual and manual inspection, but which can be used alongside these current accepted methods of pre-slaughter assessment. The first step in developing such methods is to understand where and why farmers are getting it wrong and are failing to successfully assess and send prime animals to slaughter.

1.3. REASONS FOR UNDERTAKING THE STUDY

In order to undertake the study into objective live animal assessment and selection methods, initial investigation was needed to establish the reasons why farmers are failing to get their cattle to meet desired specification. If the reasons for this failure could be understood then solutions can potentially be found to counteract this, allowing for easier and more adequate selection methods to be created which in turn will be of greater benefit to the beef industry as more carcases will attain the desired premium classifications.

1.3.1. Penalties for failing to meet desired classification

Commercial value of a carcase in the United Kingdom depends primarily on weight, conformation, fat class and distribution of the meat cuts, which now tend to be assessed both visually and through use of specialist video image analysis equipment (Fisher and Heal, 2001; Rius-Vilarrasa et al., 2009; Yeomans, 2009; Pabiou et al., 2011). Over-fat carcases which have been poorly graded through either visual or mechanical assessments whilst in the abattoir result in penalisation and a loss in profit for the producer whereas carcases of good conformation and leanness achieve a premium (Clarke et al., 2009; RPA, 2011a). In any abattoir across the United Kingdom, there are both penalties and premiums for cattle either meeting market specification or failing to reach the desired grade and this is because the consumer is willing to pay more for a product of specific quality characteristics, such as leanness (Prieto et al., 2009). Based on this, abattoirs therefore set out a pricing grid based on the EUROP system of carcase classification to set their prices and the farmers will be given a base price per kilogram of cold weight, with the grid displaying penalties for poor carcases and premiums for good (Pullar, 2001). Everitt (1966) stated that although small variations in carcass composition between animals may not appear to be significant in terms of price per cut of meat; these small variations can mean the difference between profit and loss of 226.8 kg carcase. If a carcase is too fat/thin and poorly/overly conformed then farmers can lose approximately up to 60 pence per kg of meat. However, if a carcase does meet the desired market specification, then a premium of approximately 20 pence per kg of meat is given (EBLEX, 2012b). Most abattoirs also have an upper and lower weight limit which they require cattle coming in to the abattoir to fall between. Failure to do so can once again result monetary penalties (HCC, 2012). This is why pre-slaughter selection assessments are vital in order to help reduce these financial losses to producers within the beef industry, and to minimise losses to the industry as a whole. Table 1.3 below gives a clear picture of the prices per kilogram between steers, young bulls and heifers, comparing those that achieved the prime grade of R4L with the average price received between 2008 and 2012. It is clearly seen from the table that on average, carcases reaching R4L grade received (in some cases) up to an extra 12 pence per kilogram for meeting the desired grade.

Table 1.3. Comparison of cattle types and pence per kilogram of meat over a 5 year period; showing the difference between R4L grade and overall average price

	Steers		Heifers		Young Bulls	
p per kg	R4L	Overall	R4L	Overall	R4L	Overall
2008	266.6	260.8	264.3	258.2	255.1	249.5
2009	285.5	281.1	283.9	279.0	273.8	267.1
2010	277.0	271.4	274.4	269.8	259.2	249.1
2011	314.3	308.9	312.0	307.3	303.8	291.5
2012	350.3	344.7	347.5	343.1	335.2	326.5

Source: EBLEX (2013c)

1.3.2. Lack of objectivity associated with visual inspection and manual techniques

The EUROP system of carcase classification has been greatly criticised because of the subjective method of visually assessing carcases, even when carried out by a trained assessor using photographic aids (Craigie et al., 2013). If visual analysis of the carcase itself is deemed subjective, then this can also be claimed about visually assessing the live animal with the use of photographic aids; one of the methods suggested to farmers by EBLEX in their Better Returns Programme. Visual inspection of conformation in live animals is one of the oldest methods of collecting information about cattle for the purposes of selection (Janssens and Vandepitte, 2004), be it for market or slaughter and it is also used for the purposes of body condition scoring. However, visually estimating fat class, conformation and live weight have all been shown in previous studies to be difficult, with inter and intra-reliability inaccuracies, primarily down to human error even in trained assessors. Observations that rely on visual readings and interpretation by an observer (such as visually observing and interpreting fat level in cattle) are prone to a lack of objectivity, accuracy and demonstrates that human perception can be selective and biased as our sensory perceptions do not necessarily permit us an accurate view of reality (Tuyttens et al., 2014). Wood et al. (2015) concurs with this in that they found that visually estimating live weight in cattle was highly variable in accuracy, with accuracy in live weight estimations actually decreasing as the weight of the cow increased. Alongside this, they found that the likelihood of underestimating weight was greater with larger cattle (such as those that would be reaching ideal slaughter size), thus meaning that cattle were at an ideal slaughter weight earlier than estimated by producers which would inevitably result in sending overweight cattle to slaughter based on these visual estimations. These findings suggest that the inaccuracy of visual assessment can affect management practices, such as selecting animals for slaughter or the preparation of vaccine doses as inaccurate assessment can lead to over and under-estimations of body weight and condition. This inaccuracy and lack of objectivity in selecting cattle for slaughter is one of the reasons that could explain why beef producers have a problem with sending over-fat or poorly conformed animals to slaughter.

Cabassi (1990) stated that subjective prediction systems using human evaluators lead to errors. Errors can depend on the person making the assessment and they can give different estimations on the same animal depending on, for example, the conformation levels of previous cattle assessed (Halachmi et al., 2008), therefore making visual assessments a highly subjective method of live animal selection. However there are means to help reduce the potential for these errors. For example, evaluators should receive training beforehand to decrease the variability in the results and ensure high repeatability and reliability between evaluators (Cabassi, 1990; Janssens and Vandepitte, 2004). Furthermore, Lawrence et al. (2012) state that the precision in assessing live animals depends heavily on past experience. Following on from this, findings by Phythian et al. in 2012, which assessed inter and intra-reliability of trained assessors looking at body condition in ewes found that trained and experienced assessors could reliably score body condition in groups of sheep, although a calibration exercise where re-familiarisation of different scoring categories occurred did prove beneficial in maintaining reliability. In contrast to these findings, there are studies which demonstrate that high levels of subjectivity still remain even after training and a phenomenon known as "observer drift" (where increased familiarity with a scale of measurement causes definitions between different categories/classifications to shift), resulting in inaccuracies is seen in those assessors who do not receive regular training (Martin and Bateson, 1998). These issues with very subjective methods of assessment highlight the need for a more objective method of live animal assessment, which would help to eliminate some of these potentials for inaccuracy and would allow farmers to have a better chance of sending more adequate animals to slaughter, in turn receiving premium prices for their carcases.

1.4. AIMS, OBJECTIVES AND STRUCTURE OF THESIS

The main research question addressed within this thesis was whether (using statistical techniques) a combination of live-animal morphometric and fat measurements taken prior to slaughter can be used to predict whether or not cattle will meet a UK premium carcase classification according to the EUROP system of bovine carcase classification.

In order to try and achieve this, several objectives needed to be met. The first was to look at the past in order to understand the development and history of the current EUROP beef carcase classification system. Chapter 2 looks at the development and uptake of this system used in the UK and Europe from the late 1700's up until the modern-day carcase classification system used to classify today. This chapter also takes into account how the live animals were assessed at market and asks whether what we are doing now in terms of pre-slaughter assessment has changed that much from what we were doing two hundred years ago. It is essential in helping to further understand what is desirable to the UK market and why and how this has emerged. This also helps determine what has changed in carcase classification and live animal assessment and if this has helped or hindered current pre-slaughter selection techniques. Further research on recent scientific studies and the use of morphometric and fat measurements in other countries was also carried out to justify and validate the measurements used further on within the study, with the EUROP system being compared to that of a non-European country (United States of America) to see what can be learnt from systems that don't primarily focus on conformation and fat class as a grading system. This chapter concluded with a review of the current situation and demonstrates the fundamental need for a more objective way of assessing live animals in order to suit the EUROP classification grid. The chapter then goes on to assess objective methods of selecting live cattle for slaughter which could be used to predict final carcase classification. These methods were based on previous research and scientific studies, which were analysed in order to determine the most useful pre-slaughter measurements and the easiest and least labour-intensive ways of obtaining them on-farm. All methods have previously been cited in scientific studies or used in other countries but these have not necessarily been used in conjunction with each other in helping to determine final carcase classification outcome.

Chapter 3 looked at the present-day situation and reviews and analyses a questionnaire of the current methods available to and used by beef producers to assess conformation and fat class in live animals, to find out precisely what methods farmers are using at present to determine readiness for slaughter in beef cattle. Furthermore, statistics on the number of animals across the UK achieving desired classes help to gain an understanding of success rates in meeting UK premium classes. The questionnaire took into account what methods of pre-slaughter assessment provided by AHDB Beef and Lamb that farmers are undertaking (if any), how they view their success rates of getting carcases to meet premium specification, what their actual success rates are in reality and to what extent they make use of the Better Returns Programme and Live-to-Dead days. Reviewing these methods and the current success rates in achieving desirable classes allows for any flaws in current selection methods to be identified, with the potential for these to be improved upon or rectified through the use of more objective techniques

Chapter 4 presents a thorough methodology for each of the following studies (Chapters 5 and 6) with detailed descriptions of the study samples and measurements taken from the live cattle, taking into account the materials used, housing and management facilities, abattoir feedback and data obtained post-slaughter. Finally, data feedback information and analysis tools used for statistical procedures within both of the measurement studies are discussed.

The aim the research in Chapter 5 is to see whether a relationship can be established between morphometric and/or fat measurements taken from live cattle prior to slaughter and the final carcase classification assigned. A forward stepwise binary logistic regression was used for analysis of the data, with a detailed procedure given on how these models are built up from the very basic descriptive analysis, correlation matrices, simple logistic regression and variable selection right up to the complex modelling procedures used in order to try and determine a relationship between morphometric/ultrasonic measurements and final carcase outcome. The measurements discovered in this study then go on to form the fundamental basis for the final study.

In Chapter 6, these few measurements are then tested on a wider data set; a larger study sample with a greater variety of cattle breeds identified. This helps to validate the model produced in the previous chapter and to see whether it needs to be further adapted to suit various different breeds and types of prime commercial beef cattle in order for it to be appropriate, useful and applicable to the UK beef industry.

Finally, Chapter 7 draws all the conclusions found from the three studies together, analysing and assessing the progress of pre-slaughter assessment of cattle through time, the usefulness of the findings from this research project to the UK beef industry and any potential future applications of the findings to further scientific work.

1.5. DISCUSSION

There are many justifications and reasons for undertaking this study. Failure of bovine carcases to meet desirable specification according to the EUROP classification system is shown to be an ongoing management and financial problem for the UK beef industry, and potentially the entire European beef industry as a whole. Even with current methods of pre-slaughter selection recommended and provided by the AHDB Beef and Lamb, approximately half of all carcases are failing to meet premium quality grades. Lack of objectivity in pre-slaughter selection practices could be of the reasons why so many carcases are failing to meet the grade and so this study aims to correct this through the developing and use of more objective methods of live animal assessment. In order to do so, a further understanding of what farmers are actually doing in terms of live-animal selection for slaughter, the tools they are using to assist them and their opinions on the success rates of their cattle meeting optimum classification is needed. Alongside this, how the current EUROP carcase classification grid was developed, is implemented and key factors involved in its creation and use need to be examined to ensure that any potential new methods of pre-slaughter selection are industry-facing and applicable to real-world beef production.

CHAPTER 2. LITERATURE REVIEW

2.1. INTRODUCTION

It is said that man began classifying beef animals as soon as they began trading in this particular commodity (Pierce, 1959). The creation of a beef carcase classification and grading system arises from a necessity to describe and identify a carcase using a set of standardised terms (Polkinghorne and Thompson, 2010). The current beef carcase classification system has undergone many changes and alterations over the past few centuries. The creation and subsequent adjustment of the system has led to the current carcase classification grid seen and utilised nowadays. It is through the trial and error over the years that the modern-day classification system has originated. Therefore, the aim of this chapter is to look at the chain of events and basis for the current classification system; where the flaws may lie and how the EU system compares with that from other countries.

2.2. A HISTORY OF BEEF CARCASE CLASSIFICATION AND SELECTION FOR SLAUGHTER

2.2.1. Market and Fairs (Weighing of Cattle) Act (1887 and 1891)

Nearly one hundred years after the creation of the Board of Agriculture in, the Market and Fairs (Weighing of Cattle) Act of 1887 was set up by the Royal Agricultural Society of England and called for the requiring of certain facilities (such as weighbridges) to be provided at markets and fairs for the weighing of live animals (Board of Agriculture, 1901; National Archives, 2011a) to help establish the correct price for them to be sold at. This 1887 Act was therefore the first example of mandatory live-animal measurements to be taken into account in England, when verifying an animal's price at slaughter.

Following on from the 1887 Market and Fairs (Weighing of Cattle) Act, an amendment was made in 1891 which promoted the compulsory return of cattle prices to the newly established Board of Agriculture (Board of Agriculture, 1900; Stareck, 1924). The return of prices was done on a quarterly basis although many markets were slow on the uptake and some markets went a whole quarter without actually weighing any cattle (Board of Agriculture, 1900). However, all the major markets eventually abided by the new act and this allowed for regional comparisons in prices to be made.

Price of cattle sold at market, even back at the turn of the century, was affected by quality. Grading was applied even at this early stage of carcase classification development. There were three different grades given to cattle, mainly based upon weight and how fat the animal appeared to be (Board of Agriculture, 1900), the first instance of using visual appraisal alongside live weight as a means of live-animal assessment. The first of these grades was the inferior or third quality grade, which very few animals actually came under. The second grade was the good or second quality class and this was where the majority of cattle at market fell under. The top grade, known as prime or first quality, contained the most desirable animals, and these reached the highest prices. It can be seen from the table below the difference in price for beef cattle between all three grades in both London and Perth in early 1900:

Table 2.1: Difference in Price of Beef Cattle (Price per Stone) According to Quality in Two Different Regions in 1900

Grade	London	Aberdeen
Inferior (third quality)	3 shillings, 4 and a quarter pence	3 shillings and 4 pence
Good (second quality)	4 shillings and 5 and a quarter pence	4 shillings and 3 and a quarter pence
Prime (first quality)	5 shillings	4 shillings and 8 and 3 quarter pence

Source: Adapted from the Board of Agriculture (1900).

From the table above, it can be seen (particularly from the price-reports in London) that the average price per animal between the grades differs significantly. This mimics the system seen in modern-day grading, with the more highly conformed and desirable carcases reaching higher prices than the less desirable ones.

2.2.2. The National Mark Beef Scheme

The National Mark Beef Scheme was trialled in London in October 1929; Birmingham and north-eastern Scotland in November 1929 and in Yorkshire since January 1931 (Glasgow Herald, 1931). The Scheme was the first real attempt initiated by the government to assess and classify beef according to quality, rather than just having weights and prices reported back on a quarterly basis. The assessments which were accounted for in the primary scheme included visual inspection of the live animal and of the carcase, thus ensuring the animal had reached a suitable stage for slaughter (to minimise waste) and also to ensure that fat cover was adequate but not in excess. Visual inspection also included looking at conformation of the animal and carcase as this was long assumed to be a reliable indicator of meat quality (AHDB, 2008). Once this inspection of animal and then carcase was made, the meat was graded into prime, good or standard classifications (Hansard, 1930); however, these were very subjective and more reflective of show-ring standards than of meat quality (AHDB, 2008).

The scheme was at first met by some resistance from butchers and retailers, who did not promote the sale of classified beef that bore either the Scottish or English mark (Hansard, 1930). However, this was soon over-turned through numerous public campaigns at farms, markets and abattoirs (Hansard, 1930) and eventually received guarded support from butchers, while the producers wholly backed the new initiative (AHDB, 2008). In contrast, the slaughterhouses and meat trade organisations saw the scheme as biased towards the producers, giving them premiums, and therefore it was not in their best interests to participate (Gorter and Swinnen, 2002; AHDB, 2008).

The entire National Mark Beef Scheme was reviewed (as part of the wider Agricultural Produce Act of 1928) in 1930 by the newly-formed Bentinck Committee, which was chaired by Lord Henry Cavendish Bentinck (Glasgow Herald, 1931; AHDB, 2008). The committee recommended that the trials running in London and Birmingham should continue for a further year and that more trials should be set up in different areas of the country to try and get the backing from both the slaughterhouses and meat trade organisations (AHDB, 2008). Trials were then established in Leeds, Bradford and Halifax in January of the following year (Glasgow Herald, 1931) and it therefore soon became customary throughout the country for all carcases to be assessed and classified according to the Prime, Good or Standard classifications.

2.2.3. The Livestock Industry Act (1937-1940)

It was under the Livestock Industry Act that regulations over the cattle subsidy payments came into practice, with payments to farmers differing according to whether the animal was of ordinary or quality standard (NISER, 1942). Prices were set under the new system so that farmers producing steers of a quality standard received a subsidy of 7 shillings and 6 pence per animal whereas those producing animals of an ordinary standard received 5 shillings per animal (NISER, 1942).

2.2.4. The Fatstock Guarantee Scheme (1954-1973)

Further development of the beef carcase classification system arose through the Fatstock Guarantee Scheme, established in 1954. This Scheme was originally only applied to animals at auction; however, the scheme was transferred on to carcases due to post-war conditions and an uncertain meat supply (AHDB, 2008) under the 1947 and 1957 Agriculture Acts (World Trade Organisation (WTO), 1966). Rationing of meat ceased on the 21st of July 1954 (Hayes, 2010) and so measures had to be put in place to allow for the re-creation of a successful beef industry in the UK, to ensure that the country did not become overly dependent on imports from other countries.

One method used to re-establish the UK meat industry as a successful enterprise was through the use of deficiency (or subsidy) payments. Farmers received a payment from the Ministry of Agriculture, Fisheries and Food (MAFF) only if their cattle were eligible under the Fatstock Guarantee Scheme (Hayes, 2010). This eligibility depended on certain standards of weight and conformation, assessed primarily through visual appraisal and inspection (Lyons, 1965; Everitt 1966). Cattle carcases had to meet a certain minimum weight (390 Ibs for heifers, 420 Ibs for steers) for the producer to be awarded a payment (Everitt, 1966; Hayes, 2010); however carcases of cows were not accepted under this scheme unless the animal was certified as maiden, or if the pregnancy was undetectable (Hansard, 1964), as this could compromise eventual carcase quality.

At the livestock markets, cattle were assessed by a government official. Once an animal was sold, a hole was punched in the ear of the animal to ensure that the subsidy for that animal was only claimed for once after slaughter. The animal was then assessed by the official and branded with a "C" if found to be of good beef quality and eligible for subsidy payments, or an "X" if not. The farmer would then receive a subsidy cheque in the post within seven days after slaughter (Hayes, 2010).

Steer, heifer and "clean" (maiden) cow carcases were graded to either a "Q", "A" or "B" standard (Tomlin, 1961; Roy et al., 1973; Hayes, 2010) with the grade "B" receiving the lowest price per carcase. If trade in beef was poor, then all the carcases would be given the "B" grade, at minimum price, to ensure the market picked up again (Hayes, 2010).

A problem noted with the Fatstock Guarantee Scheme and the classification of animals, as pointed out by Sir Leslie Thomas in 1964, was the decision on whether to grade a carcase as either a heifer or cow. There had been cases where a heifer which had been put to the bull, but failed to conceive, went to slaughter and was declared by an official as a once-pregnant cow and therefore the farmer lost out of the deficiency payment (Hansard, 1964) as the animal was marked with an X. The carcase would then go on to be correctly graded as a Grade B heifer post-slaughter, meaning that the farmer should have received a payment after all (Hansard, 1964). This therefore highlights the problem in judging and grading live animals and carcases according to the Fatstock Guarantee Scheme, a problem which needed to be addressed to ensure that all farmers and producers got the deficiency payments they required from their animals. This lack of communication between producer, abattoir and market lead the government to assess the need for a “freer” market to be established (AHDB, 2008) to allow for more clarity in the industry.

2.2.5. The Meat and Livestock Commission (1967-2008)

The Meat and Livestock Commission was originally created under the Agriculture Act of 1967 on the 1st of October in 1967 with the main purpose being to help standardise a national system of carcase description in terms of features of interest to people trading in either the live animal or carcase and to promote efficiency within the livestock industry (Radcliffe, 2005; AHDB, 2008; National Archives, 2011a). Once the Commission was established, it was first noted that the three terms most commonly used to describe carcases by producers were fat level, conformation and weight and that these three observations could be used to predict overall meat yield (AHDB, 2008). It was through the acknowledgement of the common use of these three terms within the early UK beef industry that the classification system currently used today was developed, and it is through the use of fat level, conformation and carcase weight that farmers are now paid through the system used today.

2.2.6. Launch of the Beef Classification Scheme (1972)

The launch of the pilot Beef Classification scheme occurred in 1972 and involved common, widespread use of a nationally agreed dressing specification to be used when weighing carcases, along with visual appraisal of conformation and fat level, in conjunction with the category and age of the animal (AHDB, 2008).

In 1974 Beef Classification Scheme was officially recognised as a new national scheme and the main aim of the scheme was to provide a foundation for which all adult bovine carcases could be described under shared terms across the United Kingdom (Fisher, 2007; AHDB, 2008; Rius-Vilarrasa et al., 2009). However, there was some significant opposition to the new scheme, with some holding the view that these "new" methods actually offered nothing towards improving efficiency within the sector (Preston and Willis, 1974) and were therefore unnecessary. In reaction to such views, the MLC pushed that this national system would not only provide standardisation, but also enable better price-reporting amongst abattoirs and encourage the breeding of animals with better quality carcases, which were more suited to the desired market specifications. The use of classification abattoirs increased as it became compulsory under certain EU schemes (AHDB, 2008; Rius-Vilarrasa et al., 2009). It was through the use of promotional materials, activities and literature provided and advertised by the MLC that by 1976, approximately 45% of the national kill within the UK was classified using the new classification scheme (AHDB, 2008). However, while the scheme was adopted by nearly half of the country, there was little use of the information recorded by the scheme, in that it was rarely used to actually price carcases. There was also a lack of communication between the slaughterhouse, wholesaler, retailer and consumer (AHDB, 2008), meaning that no one was actually sure what characteristics were desirable in a beef carcase and subsequently, the live animal.

One of the reasons as to why there was a lack of dissemination of information between members of the beef industry in regards to beef classification was down to the use of MLC Fatstock Officers within the abattoir. When the pilot scheme was first launched, coincidentally, these officers were already present in the abattoir, undertaking carcase inspection to determine suitability for subsidy payment (AHDB, 2008; MLCSL, 2009). This meant that classification under the pilot scheme was often carried out as an extra exercise while they performed their subsidy inspections, normally under no extra cost; meaning that while the abattoir accepted the classification, they had no obligation to utilise any of the information recorded (AHDB, 2008). Although slow on the uptake and even slower on the utilisation of the information gained, this new Beef Classification Scheme was an improvement on the Fatstock Guarantee Scheme with more emphasis placed on the need for a working classification system that was to be adopted by all levels of the beef production chain. In table 2.2 below, the carcase classifications for this initial scheme (pre-1981) are shown, with an obvious development from the “Q,” “A” and “B” categories which were the standard back when the Fatstock Guarantee Scheme was in place.

2.2.7. Pre-1981 Carcase Classification

Prior to the setting up of the European Union in 1992, several European countries were already executing their own classification systems in the late 1960s and early 1970s, but were all fundamentally based on similar carcase characteristics, such as weight, conformation, fat class, age and gender (Fisher, 2007). However, the number of fat and conformation classes between the countries varied, with Britain having five classes for each, but with countries such as Germany having 3 classes for fat level whereas Ireland had seven (Fisher, 2007; AHDB, 2008). Due to many carcases falling into the middle class of 3 for fat level within the UK, this was then further split into lower and higher bands by the Meat and Livestock Commission. A further class (Z) was created for those animals which were too poorly conformed to fall into the usual 1-5 conformation classes (Fisher, 2007). A summary of the pre-1981 beef carcase classification system is shown below, alongside the corresponding classifications used in the post-1981 beef carcase classification system:

Table 2.2: Pre and Post-1981 Beef Carcase Classification Systems used within the UK

Conformation		Fat Class	
MLC (pre-1981) Classification	EEC (post-1981) Classification	MLC (pre-1981) Classification	EEC (post-1981) Classification
5	E, U+	1	1,2
4	-U	2	3
3	R	3L	4L
2	O+	3H	4H
1	-O	4	5L
Z	P	5	5H

Source: Adapted from Fisher (2007).

2.2.8. Emergence of the EUROP System of Beef Carcase Classification (1981)

The EUROP system that is used today to classify bovine animals officially emerged on the 28th April 1981 under the European Council Regulation 1208/81 and was adopted by Britain on the 9th November of the same year (Fisher, 2007; Pabiou et al., 2011). It was under the European Management Committee for beef and veal that the rules of classification were discussed and disseminated between EU member states, with only small variations in classification systems seen between countries. However, it was not actually compulsory to other EEC member states until the 1st of October 1982, under the European Council Regulation 1208/81 (standardised scale of classification for adult bovine carcases) and Commission Regulation (EEC) 2930/81 (adopting additional provisions for the application of the community scale for the classification of carcases of adult bovine animals), and is now seen in approximately 27 member states (Pabiou et al., 2009).

2.2.9. The Beef Carcase (Classification) Regulations (1991)

The mandatory Beef Carcase (Classification) Regulations (1991) were fully implemented on the 1st of January 1992 following the previous introduction of Council regulation (EEC) No 1208/81 and by Commission regulation (EEC) No 2930/81 (SI 1991: 2242; AHDB, 2008; MLCSL, 2009) The new regulations stated that all bovine carcases were required to be classified according to the agreed EUROP classification system (SI 1991: 2242). Results of classification must be returned to the person who sent the animal to slaughter and that classification of carcases can only be carried out by those qualified to do so, carrying a licence that complies with the Beef Carcase (Classification) Regulations. (SI 1991: 2242). It can be seen from the 1992 regulations that the main aim of the implementation was to allow for clarity between abattoir and farm through dissemination of final classifications, ensuring classification remained as standardised as possible. This regulation was amended in 2003 under Commission Regulation EC No 1215/2003 and permitted the use of automated assessments (such as video image analysis), providing they have been proven using statistical methods. Modifications to any automated assessment tools could be made, providing they improved the accuracy of carcase classification (Europa, 2012b). This amendment could therefore potentially mean better standardisation in carcase classification in those abattoirs with automated assessment tools.

2.2.10. Video Image Analysis

Video Image Analysis (VIA) is an automatic and objective means of assessing the conformation, fat and saleable meat yield in carcases using video cameras to take digital images of a carcase which are then processed by a computer to extract data relating to the carcase conformation. Fat level is then analysed through the intensity of grey shading across the carcase and this information, along with that obtained from carcase dissection can then be used predict estimations of carcase yield (Maltin, 2010), as well as providing the carcase classification according to the EUROP grid.

VIA was originally developed for beef carcase evaluation in the United States of America in the early 1980's following a project beginning in 1978 by the USDA and National Aeronautics and Space Administration and Jet Propulsion laboratory to develop a tool for the objective evaluation of carcass quality and yield grades (Cross et al., 1983). VIA can be used on a whole or half a carcase prior to entering the chiller and also on the quartered carcase after chilling has taken place (Craigie et al., 2012) and is also used to predict the saleable meat yields of ovine carcases as well (Rius-Vilarrasa et al., 2009). Back in the 1980's, the most accurate method of measuring and assessing fat content of a beef carcass was through chemical analysis (Newman, 1984a), although this was too costly and time-consuming for commercial usage. However, Newman (1984a) found that comparisons between the data collected from chemical analysis that that collected from the use of VIA had a good correlation, thus showing that VIA was a viable tool to be utilised determining fat assessment in beef. Further studies undertaken by Newman once again found that results found from VIA were comparable to those found using chemical fat analysis and that VIA could be used reliably within a commercial environment. However, when compared to visual assessments, results from VIA did differ significantly (Newman, 1984b), which concurs with more recent research by Craigie et al. (2012) who found that VIA has much greater repeatability than visual assessment methods alone. Rius-Vilarrasa et al. (2009) also found that when compared to the EUROP carcase classification scheme (assessed visually in carcases), VIA was much more capable of improving the prediction of primal meat yields. The current commercial VIA systems used in abattoirs today were developed in the 1990's have the advantages of being fast, objective and totally automated when used for whole sides of carcases, thus eliminating the need for human assessors and therefore improving objectivity and accuracy (Maltin, 2010; Craigie et al., 2012).

Whole-side VIA is used to predict carcase conformation and fat class according to the EUROP system in the EU, but before a VIA machine can replace visual assessors, the machine must be validated against a panel of five trained assessors to determine its reliability for use in a commercial environment (Craigie et al., 2012). The use of VIA within UK and other European abattoirs is becoming more common, however implementation of image analysis for use on beef carcases can be problematic as variations between genotypes and production systems has given rise to great differences between bovine carcases (Oliver et al., 2010), of which the VIA system needs to account for. Other European countries including Ireland, Denmark and Germany have also begun to adopt VIA in order to enhance bovine classification with the EUROP system (Allen and Finnerty, 2001; Maltin, 2010), however different makes of VIA machines have also been shown to vary in their accuracy at predicting meat yield, possibly due to having to be calibrated using human assessors instead of quantifiable characteristics, which means that use of VIA is not yet a completely foolproof way of assessing bovine carcases (Allen and Finnerty, 2001) and that a better system of validation for these machines is needed (AHDB, 2008).

Video Image Analysis may never totally replace manual classification as for some abattoirs (particularly the smaller ones) it will never be a cost-effective investment (Maltin, 2010). In contrast to this however, it does allow for those larger and more commercial abattoirs a greater potential to improve the accuracy of the information on carcase classification and meat yield given back to producers, although more work is needed on improving the standardisation and validation of using this method. In 2014, Anglo Beef Producers (ABP), one of the largest beef producers in the UK announced that they were switching all their abattoirs to a VIA system and furthermore, that they would be implementing a 15-point carcase classification grid in order to allow for greater detail in carcase classification to better reward those that met desirable classes (Nicolson, 2014). This progress in carcase classification techniques mean that live animal selection needs to be even more specific, objective and accurate in order to ensure that the eventual carcases achieve those desirable UK premium classifications. It highlights the need for the development and progression of live animal selection in order to match the improvement of the carcase classification system.

2.2.11. UK beef carcase classification: current organisational structure

The Agriculture and Horticulture Development Board (AHDB) was set up in 2008 and is a statutory levy board independent of the Government, funded by farmers and growers and owns the Meat and Livestock Commercial Services (MLCSL) business which operates within the red meat industry within the UK, which was derived from the original Meat and Livestock Commission (Radcliffe, 2005). The MLCSL provides an authentication and classification service within UK abattoirs and classifies over 80% of all cattle slaughtered in Britain each year (MLCSL, 2009). The MLCSL is accredited by UKAS (United Kingdom Accreditation Service) (MLCSL, 2009) which is the only national accreditation service recognised by the government to assess against internationally agreed standards (UKAS, 2012); in this case, against the EUROP system of carcase classification. This ensures that any animal classified by the MLCSL complies with EU carcase classification regulations.

The AHDB was originally split into 6 divisions operating within the UK, with one division being English Beef and Lamb Executive (EBLEX) (AHDB, 2012). The aim of EBLEX is to promote research and development within the beef and lamb industries and one of their schemes includes providing manuals to aid farmers in selection of animals for slaughter, giving visual aids for farmers to use to help assess their animals, as well as online tools and abattoir visits to view the livestock pre and post-slaughter. EBLEX was renamed and rebranded as AHDB Beef and Lamb on June 10^{th} 2015 as part of a collaboration to get all six divisions under the Agriculture and Horticulture Development Board to become more unified, however their goals to benefit and improve the beef industry (and other sectors) remained the same (AHDB, 2015). In regards to the current classification of bovine carcases, the Rural Payments Agency (RPA) is directly responsible for the enforcing of the current EUROP beef carcase classification scheme in UK abattoirs, as well as issuing licenses to qualified classifiers and conducting inspections on abattoirs (RPA, 2012c).

In terms of the future of the British beef industry and the carcase classification system used today, the effect of Brexit on the UK and the beef sector may result in a total overhaul of the EUROP carcase classification grid, to create a grading system more suited to the breeds of cattle seen most commonly in the UK. It is therefore useful to find out what other non-EU countries are doing in terms of carcase classification and pre-slaughter selection, as these may go on to form a basis for a potentially new beef carcase classification system used in the future.

2.2.12 Discussion

The EUROP system of beef carcase classification has evolved rapidly over the past one hundred and fifty years into a generally well-trusted tool for beef carcase assessment. The ongoing development of the EUROP system of beef carcase classification has created a system which is trusted by both the abattoirs and producers of beef for the sale of finished cattle carcases. In the future there may be a need for additional quality measures to be incorporated into the current classification system, such as the assessment of meat quality, as seen in the USDA system. However, it has been noted in the Agriculture and Horticulture Development Board Review in 2008 that perhaps aspects of meat quality should fall under certain beef assurance schemes and therefore remain a separate entity to the classification system. It can be therefore be stated that the EUROP system for beef carcase classification has been well suited to what the UK beef industry requires in terms of carcase feedback and is currently an effective means of post-slaughter assessment and categorisation of bovine carcases. Whether this will be the case post-Brexit remains to be seen.

The new technology available for carcase assessment (such as Video Image Analysis) is potentially allowing for greater accuracy in terms of carcase classification through the use of more objective measures of carcase assessment, although some more work is needed to ensure that mechanical assessments of carcases are standardised throughout the UK beef industry (especially in terms of fat level assessment). With the emphasis and research beginning to focus more on objective measures of carcase assessment than on the traditional, subjective, human assessment, there are therefore potential benefits in investigating the use of objective measures (such as morphometric and weight recording) in the assessment and selection of live animals prior to the slaughter and carcase classification process in order to increase the number of carcase achieving a UK premium outcome.

2.3. METHODS OF LIVE-ANIMAL ASSESSMENT

Determining when cattle are in prime slaughter condition has been a difficult and controversial issue within the UK beef industry ever since the classifying of carcases first began and has therefore been the topic of much scientific research and investigation. It is known that if farmers meet specific grades on the EUROP grid of carcase classification then premiums for that carcase are received. Consequentially, failure to meet prime market specification results in significant financial losses to the beef producers, as well as overall losses UK beef industry (EBLEX, 2012a). Annual data provided by EBLEX indicates that each year approximately only half of all beef carcases meet prime market specification (EBLEX, 2012d; AHDB, 2015), thus leaving 50% of all cattle sent to slaughter either too fat, poorly conformed, or combinations thereof. This data provided by EBLEX (now known as AHDB Beef and Lamb) indicates the necessity of finding a more objective means of live-animal assessment to help identify prime slaughter condition in commercial beef cattle, in order to ensure that cattle sent to slaughter meet market specification. It is therefore of significant interest to the industry for techniques which assess the conformation and fat class of cattle prior to slaughter to develop (Peña et al., 2014). Recording of live-animal statistics (such as weight and height) are well known to be good practices for assessing the morphology of cattle and can reveal part of the economic value of the eventual carcase (Alonso et al., 2007). Alongside this, other countries such as Australia already use ultrasonic fat readings of specific body regions to determine fat depth in a live animal as a predictor of carcase quality grade (Wall et al., 2004; McKiernan and Sundstrom, 2006), thus justifying their potential to be utilised within the UK industry. Using this evidence, there is subsequently the potential for a range of objective physical body measurements taken from live cattle prior to slaughter to help predict and determine prime slaughter condition in commercial beef cattle in the UK. Furthermore, greater investigation is needed into past research and use of these body measurements in conjunction with carcase assessment, both within other countries and scientific studies in order to account for their inclusion in this project. The aim of this chapter is to therefore look at the potential live animal measurements selected for the study, to see their history and current use both within industry and scientific research, in order to justify their use within the project.

2.3.1. Live-weight and weight recording

The oldest and most "traditional" method of determining readiness for slaughter in cattle is the recording and analysing of live-weight. Not only this, the assessment of live-weight is one of the most accurate, objective and easy factors to measure on-farm through the use of weigh scales and is shown to have a strong correlation with final carcase weight and meat yield (Razook et al., 2001; Wall et al., 2004). However, this is only valid providing the scales are calibrated correctly prior to measuring in order to avoid basic errors and inaccuracies in the readings (Robinson, 2005; Wood, 2015). One of the main disadvantages to using live-weight as a method of live-animal selection is the cost associated with the purchasing of the weigh scales, with the average price of a weigh bar being around £775 (Braymont UK, 2018), however if weight does have a good relationship with carcase classification and helps to select the most suitable animals for slaughter, then this will consequently save the farmer a significant financial loss in the future. Furthermore, the regular recording of live-weight also allows for producers to estimate the finishing period and make adjustments in diet to compensate for any weight fluctuations.

It is well known throughout the beef industry that optimal slaughter weights vary significantly across different cattle breeds (Long et al., 1979). However there are penalties associated with weight, particularly with heavier cattle, and EBLEX (2011) also clearly state that cattle should not be marketed on weight alone. Relying on live-weight only to determine readiness for slaughter does not give an indication as to the carcass composition, conformation, or body fat content (Little and McLean, 1981) and so using live-weight alone for slaughter selection is fundamentally flawed and will result in financial losses if no levels of either conformation, fat or type are taken into account (Alderson, 1999), particularly as Bowden (1962) stated that there was no relationship between the rate of weight gain and conformation of an animal. Furthermore, live-weight can vary according to time of day, due to differences in gut fill and water retention (Anderson and Tietjen, 1982; Robinson, 2005) with gut fill potentially accounting for up to 22% of total live weight (Wythes, 2012). This means that although an animal may appear to be at a specific "desired" weight when weighed, nearly a quarter of this could be made up of stomach contents, rather than of lean muscle and fat, which clearly demonstrates another problem with sending cattle to slaughter based purely on live-weight alone.

Bearing this in mind the use of live-weight, prior to the morning feed to ensure gut fill does not impact significantly on the reading (Harris, 1967), should therefore be in conjunction with other objective measures of live-animal assessment (such as ultrasonic fat depth readings or morphometric measurements) to take into account differing conformation and fat levels which can have an influence on final carcase classification. Only when cattle are of the right weight along with the correct body shape and fat level should they then be sent to slaughter to ensure optimum returns.

2.3.2. Ultrasonic Fat Depth Readings

Williams (2002) described ultrasonic fat measurements as a “non-invasive estimation of the accumulation of fat build-up in a live animal” and have been used as far back as the 1950’s to assess body composition in cattle (Ribeiro et al., 2014). Ultrasonic fat readings are a means of rapid and precise determination of the carcass composition in live animals and can therefore be used effectively to sort for slaughter (Peña et al., 2014). In 2005, Diaz et al. demonstrated that objective fat measurements in lamb carcases correlated more with carcass fat measurements than subjective measurements (such as visual appraisal) and this also concurs with Cabassi (1990) who showed that objective measurement provides the best predictions of the composition of carcases. Furthermore, studies by Wall et al. (2004) and Conroy et al. (2010) found that the use of ultrasonic techniques were most effective at predicting carcase outcome the closer to slaughter they were used, with 24 hours being the optimum. The usefulness of such techniques as an aid to predict carcase composition decreased as the period before slaughter in which they were applied was increased.

Ultrasound scanning has the potential to be used as a non-invasive, pre-slaughter technique of which to assess the composition and fat depth in cattle, however the reliability and accuracy of the tool does depend on factors such as the skill of the technician and the choice of instrument used (Peña et al., 2014). The physical scanning points on the live animal also need to be taken into account, to ensure that should this method be used as part of the on-farm tool, the ease of taking the measurement is practical, easy and not labour-intensive.

2.3.3. P8 fat point

The P8 fat point is measured in millimetres and is assessed using an ultrasound scanner (Littler, 2007). In New South Wales, Australia, the P8 fat point plays a major part in the physical assessment of a live cattle, with a fat score assigned to an animal according to the fat depth recorded at the P8 site by an ultrasonic reader (Littler, 2007). The fact that the P8 point is already used as a measure of live animal assessment in Australia indicates that this is a reliable, objective and accurate method of assessing cattle for slaughter. The P8 site is situated in the sacral region between the tuber ischii (pin bones) to the tuber coxae (hook bones), which then corresponds to the beginning of the first coccygeal vertebrae (Knee, 2006; Schröder and Staufenbiel, 2006), making it an easy-access point to measure when cattle are restrained within a crush. Figure 2.1 below shows the exact point of which the reading should be taken from cattle:

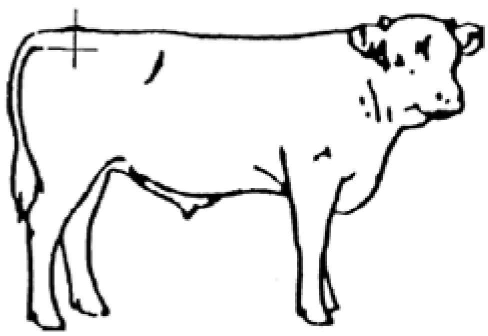


Figure 2.1: The Location of the P8 Point in Cattle

Source: Knee (2006).

In Australia, an animal is generally in prime condition for slaughter when the P8 fat point reads at either 7 or 8mm (McKiernan and Sundstrom, 2006) and this measurement can be taken up to a week prior to being sent to the abattoir yet still maintain accuracy, to ensure minimum disturbance and stress to the animal prior to slaughter (Robinson and Oddy, 2004). P8 fat depth in a carcase has also been shown to be a good indicator of overall carcase fat content in a variety of commercial cattle breeds (Taylor et al., 1996) and this could therefore mean there is a potential relationship between the P8 reading and final fat class assigned to the carcase. In the table below, it can be seen that live animals with a P8 fat reading of between 0 and 2 millimetres are considered too lean for optimum market specification whereas those with a reading of above 12mm are considered too fat (Knee, 2006), both of which could result in financial losses. The level of fat at the P8 point can also be estimated through physical handling techniques and visual assessment and Table 2.3 below shows what is felt for at different levels of fat thickness at the P8 site, according to Knee (2006):

Table 2.3: Handling assessment of fat depth at the P8 point

Fat Thickness	Assessment Key
0 – 2mm	Hip bone visible and hard. No fat in brisket or flank. No filling in anal fold. Spine felt over rump.
3 – 6 mm	Hard hip bone. Light fat deposit in flank and brisket. Anal fold soft-feeling. Spinal vertebrae felt but feel rounded.
7 – 12 mm	Hip bone has soft tissue feel. Obvious fat in flank and brisket. Thick, spongy anal fold. Spine cannot be felt.
13+ mm	All bone structure covered in fatty tissue. Anal fold very full.

Source: Adapted from Knee (2006).

Although this table is useful for giving a general estimation of fat depth at the P8 point, it could be said to be subjective and inflexible with a lack of distinction between each individual millimetre meaning that the range between each score could be too wide to suit a particular market (Cabassi, 1990). This could again result in financial losses through sending an animal which is too fat (or not fat enough) as the range of measurements is not specific enough down to the nearest millimetre. Furthermore, this system of fat scoring involves grouping into discrete variables, whereas fat level itself is a continuous variable and so defining the boundary lines between groups could be problematic (Cabassi, 1990). However, this table may potentially be useful to those farmers who might not have access to an ultrasound scanner and could therefore potentially be adapted for those UK farmers who also lack access, through use in collaboration with simple manual handling of specific fat points to estimate fat depth.

To use the P8 fat point in the creation of an on-farm tool for live-animal assessment, a strong relationship either needs to be seen with this form of measurement and carcase classification according to the EUROP grid, either as a stand-alone measurement or in conjunction with other methods. The ultrasonic reader needed to take the P8 fat reading from live cattle is quite costly, with the average price being around £500 (Renco Corporation, 2009) so in order for farmers to take up this method and buy the equipment required, a strong justification for its use needs to be found, with this justification being that the P8 point is useful in assessing live cattle prior to slaughter. However, just because the P8 fat point relates well to the Australian system of live animal assessment and carcase classification does not necessarily mean it can be transferred across to the European one, due to subtle differences in perceptions of what makes a prime beef animal. Alternatively, should this type of ultrasonic fat reading be deemed useful and appropriate to the European system, it can then be used in conjunction with other measurements (perhaps those taking into account conformation measures) to see whether the creation of an objective, live-animal assessment tool is plausible.

2.3.4. 10th rib fat point

The 10th Rib fat point in cattle is found by counting (inclusively) four ribs in from the furthest posterior (13th) rib and 18cm down from the spine, with this being another relatively easy-to-access region in cattle restrained in a crush. This location was chosen for the study as research by Bass (1981) found that this region could objectively predict carcass fatness in beef cattle when compared to other readings along the 10th rib. Again, due to this being an objective measurement through the use of an ultrasonic fat reader, the reading given should be accurate and repeatable, although the initial price of the reader can be quite expensive (approximately £500) so there needs to be a strong justification to farmers for buying the equipment (Renco Corporation, 2009). Nowadays the 10th rib site is used primarily in post-slaughter analysis of beef carcases during cross-sectional and whole-carcass compositional analysis, but with this research suggesting that it is a good predictor of final carcase composition (Oliván et al., 2001; Font-i-Furnols et al., 2014), it is worth investigating this site further see if it can help determine suitability for slaughter in live animals. Figure 2.2 below demonstrates where both the 10th and 12th ribs are found on cattle, and the location for the ultrasonic device when taking the reading.

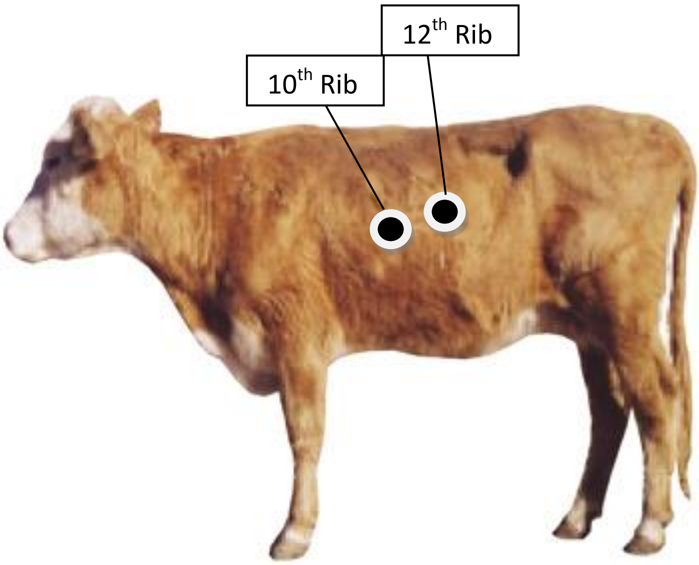


Figure 2.2: The Location of the 10th and 12th Rib Fat Point

Source: Adapted from Bass (1981) and New Mexico State University (NMSU) (2002).

2.3.5. 12th rib fat point

The 12th rib reading is taken on the second most posterior rib (see figure 2.2 above) with Cabassi (1990) taking a 12th rib reading 11 centimetres from the spine in sheep carcasses when objectively assessing fat depth. The 12th rib fat point reading is also used in Australia, alongside the P8 fat point, in order to help determine fat depth in live cattle and suitability for slaughter (McKiernan and Sundstrom, 2006), with the relationship shown in table 2.4 below. Due to the location of the site of the 12th rib, this is again an easy point to measure with the use of an ultrasonic fat reader in cattle restrained in a crush.

A study in 2004 by Wall et al. also found the ultrasonic reading taken at the 12th rib was one of the more accurate and useful predictors of quality grade in a beef carcase and the 12th-13th rib region cross-section was found to be better at predicting rib composition than that of the 9th-10th rib cross section (Santos et al., 2013). Further to this, 12th to 13th rib fat thickness was also shown by Aiken et al. (2002) to increase linearly with average daily gain in yearling steers after corn supplementation, thus demonstrating the relationship between this particular fat reading and growth of the animal. Furthermore, in a study by Taylor et al. (1996), it was found that the 12th rib fat reading in a variety of commercial bovine carcases was a good indicator of overall carcase fat content, thus indicating a potential relationship between the 12th rib reading in live animals and the EUROP fat class assigned to the carcase, hence its inclusion in the study.

Table 2.4: The New South Wales Fat Score Table for Beef Cattle based on the "Rump to Rib" Ratio

NSW Fat Score	P8 Fat Point Reading (mm)	12th Rib Fat Point Reading (mm)
1	0-2	0-1
2	3-6	2-3
3	7-12	4-7
4	13-22	8-12
5	23-32	13-18
6	32+	18+

Source: Adapted from McKiernan and Sundstrom (2006)

2.3.6. External methods of fat assessment

External methods of measuring body fat in cattle are potentially of great use as an objective measure of live animal assessment as they do not require as specialised equipment as the ultrasonic methods and may therefore be more suitable for smaller farms with limited access to ultrasound devices. These methods of fat assessment require use of skin calipers and two have been selected for further research, these being anal skin fold and brisket skin fold thickness.

2.3.7. Anal skin fold thickness

The measuring of anal skin fold thickness to help determine readiness for slaughter in beef cattle was used frequently during the 1970's and 1980's, as well as being a recommended site for physically assessing the level of fat by the Victoria State Government in Australia who say that should the anal fold feel dense and spongy then there is a high proportion of fat, whereas being able to feel two individual skin layers indicates too little (Knee, 2006). The anal fold is measured using calipers to determine tissue thickness and were used in a study by Cabassi (1990) to determine the fat level in lamb carcasses. However in 1986, Somervaille et al. found that anal skin fold thickness related poorly to carcase back fat depth in cattle and nor was this measurement reliable or repeatable between assessors. This is in disagreement with a previous study in which the use of calipers was found to have an accuracy of predicting carcase fat and lean in live steers close to that of the predictive power given to the 12th rib measurement of the carcase (Johnson and Davis, 1983), as well as being a relatively cheap piece of measuring equipment to purchase. Furthermore, anal fold thickness was shown in a later study by Johnson and Davis in 1991 to be the most accurate predictor of carcase composition, along with fasted live-weight. Research by Nicholson and Little (1988) concluded that the anal fold reading was also a good way of monitoring the on-going nutritional status of the animal, thus linking it to the growth and development of cattle which could indicate an optimum thickness for slaughter.

In a study by Charles in 1974, anal skin fold was used as a more objective method of assessing body fat content in cattle than traditional condition scoring as when pinched with a Caliper, the anal fold is made up of the skin and subcutaneous fat found between the base of the tail and the tuber ischii (pin bone) and this gives an indication as to the level of fat within the animal's body. However in 1988, Nicholson and Little found that using a Caliper with only one operator was rather difficult in that the subcutaneous fat would pull away from the skin and was hard to hold while undertaking the measurement, thus accounting for the lack of reliability and repeatability seen in the Somervaille et al. study two years previously. It was from this that they therefore developed a two-operator technique in which one operator would pinch the skin while the other took the anal skin fold reading with the Calipers. The problem with this method is that in requiring two persons to take the measurement in order to ensure accuracy and a reliable reading, the labour cost is doubled. This could potentially be an issue on smaller beef farms with limited staff. However with the past scientific research backing the use of this measurement as a predictor of carcase composition, it is well worth looking into this fat measurement further to see if it has applicable use in modern day slaughter cattle selection.

2.3.8. Brisket skin fold thickness

The brisket region on cattle is the dewlap of skin and fat found extending from the lower neck and between the forelimbs, consisting of little muscle and is often used when visually assessing the body condition of beef cattle as excess fat shows clearly within this region, with it becoming fuller with increasing fatness (Knee, 2006; McKiernan and Sundstrom, 2006). The ideal brisket is said to hang just above the knee joint and should be partially filled, indicating desirable fat content across the animal (Knee, 2006). The brisket skin fold thickness in cattle is measured using calipers (like the anal skin fold measurement) and the measurement should be taken at the most ventral point, which is normally situated just in front of the forelimbs (Lawrence et al., 2012), making this a slightly more difficult measurement to take, particularly if working alone on-farm. It is through the identification of increasing brisket size in cattle which indicates an increasing level of fatness (Barham et al., 2011) which then leads on to the assumption that therefore brisket skin fold thickness must have some form of relationship with final carcase classification, given the fat level makes up 50% of the final class assigned.

2.3.9 Morphometric characteristics

Morphological descriptions of cattle have been used in past research to indicate breed origins, size or weight, with certain linear measurements having previously been used as prime indicators of weight in cattle (Alderson, 1999). Morphometrics in cattle have also been used to assess growth rate, feed utilisation, maturity, proportionality and carcase characteristics and can be divided into two types: Skeletal (height and length measurements) and tissue (girth and width measurements) (Essien and Adesope, 2003; Bene et al., 2007). Morphometric measurements have been said to be more useful than weight alone as they take into account desirable conformation aspects, such as length and width (Alderson, 1999). However, individual measurements alone have not been shown to be effective in providing farmers with reliable assessments of their animals and so some previous studies have combined a range of morphometric measurements in order to try and improve the accuracy of evaluating both body weight and type in commercial and rare breed beef cattle (Alderson, 1999).

2.3.10. Heart girth

Heart girth (also known as chest girth/circumference) is the total distance around the chest of cattle, positioning the tape measure directly behind the forelimb, vertically at the point of the elbow and then encompassing the chest area (Wood et al., 2015), as displayed in figure 2.3 below:

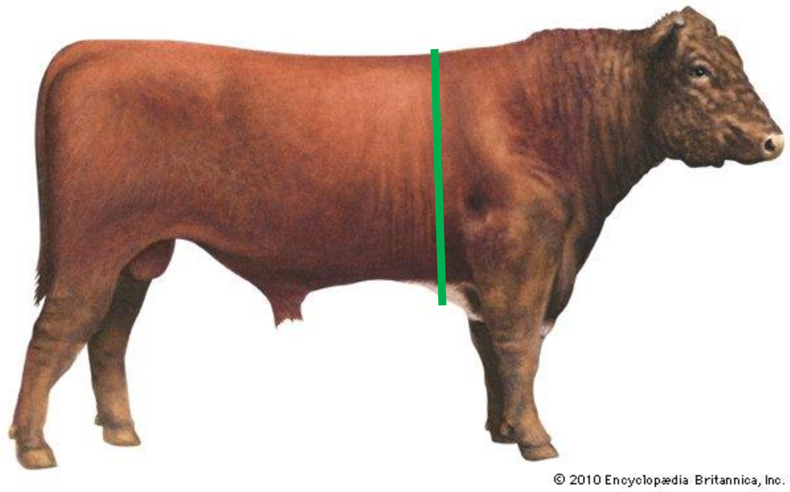


Figure 2.3: Correct Placement of the Tape Measure for Measuring Heart Girth

Source: Adapted from Encyclopaedia Britannica (2010); Wood et al. (2015).

Heart girth (although being one of the more cheaper measurements to take from live cattle) can be quite awkward to take on-farm and is often easier to take with more than one person present, which can be quite labour intensive if measuring a large group of cattle. However, many studies have found heart girth to be highly correlated with body weight in cattle of both beef and dairy varieties (as well as wide use within the equine industry for predicting live weight) and heart girth is often used as a management tool to predict body weight and therefore aid in ration formulation and health monitoring of cattle herds (Alderson, 1999; Goe et al., 2001; Heinrichs et al., 2007; Swali et al., 2008). A study by Katongole et al. (2013) found that heart girth was the only single accurate predictive variable of estimating body weight in *Bos Indicus* cattle, and in sheep heart girth has been found to have a high correlation with weight which allows for accurate estimations of live weight in the animal. Concurring with the Katongole et al. (2013) study, heart girth again displayed a stronger correlation with weight than other measurements such as wither height and scapuloischial length (Atta and El khidir, 2004). However, previous research by Alderson (1999) has contradicted this by stating that it is pelvis width which provides the most accurate predictor of live weight in cattle. A link has also been demonstrated between heart girth and carcase conformation according to the EUROP grid. Coopman et al. (2004) found that the average heart girth between double-muscled Belgian blue bulls differed between S and E classes, with the average heart girth for S conformation being 228cm and E being 213.6cm. Although this study focuses on one breed alone, and an extremely double-muscled breed at that, it does indicate that there could be substantial differences between the average heart girths of cattle at differing conformation levels according to the EUROP grid.

It is this connection with live weight which means that heart girth potentially provides a valuable tool in live animal assessment and determining suitability for slaughter. With abattoirs penalising too heavy or too light carcases and not all farms having access to weigh machines, the ability to estimate weight through heart girth and simultaneously potentially linking this measurement to final carcase classification would prove a highly valuable asset for the UK beef industry.

2.3.11. Back length

There are many variations in different studies as to what constitutes the actual back length measurement. Sandford et al. (1982) describe it as the distance between the shoulders and the ischium whereas Sulieman et al. (1990) claim it to be the distance from the top of the shoulders to the pin bones. However, neither of these two studies appear to have taken into account ease of measurement when taken on farm (in particular, identification of landmarks) or the positioning of the most desirable cuts. Taking the back length measurement from the centre point of the scapula (shoulders) as suggested by most studies, and then along the spine and subsequently ending at the second caudal vertebrae just in front of the tail head allows for easy identification for measuring purposes as this is the most prominent vertebrae (see figure

2.4 below). This also accounts for all of the prime loin cuts and can be used to see whether longer cattle attain better carcase classification.

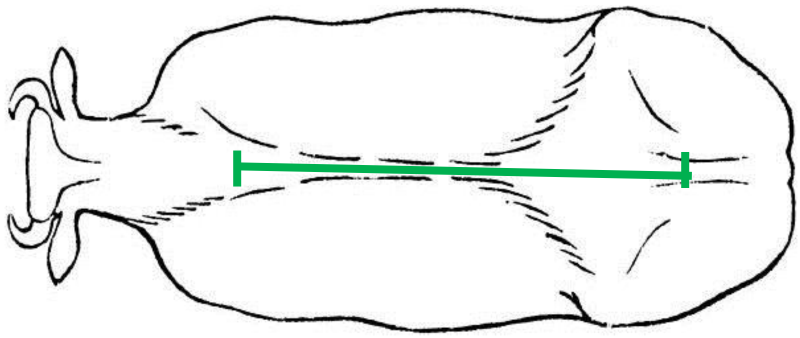


Figure 2.4 Top View Positioning of Tape Measure for Back Length Measurement

Source: Adapted from Allen (1865).

Longer carcases have been associated with a higher growth rate and a decrease in intramuscular fat content, which is desirable in the health-conscious society of today although in the same study Aass (1996) found that this is directly related to poorer dressing percentage and fleshiness. Furthermore, in 2003 Piedrafita et al., found that longer carcases had a tendency towards poorer conformation, although they found the longer carcases had a higher fat content within. With modern breeders focusing on increasing the length and size of their animals (Bene et al., 2007), there is therefore a need to establish whether in fact longer commercial UK beef cattle are still associated with poorer carcase quality at slaughter as then emphasis could be placed on farmers to select for shorter cattle and/or send them to the abattoir before too much non-beneficial growth has occurred, thus increasing the chance of the animal meeting a desirable carcase classification, yet potentially leading to a lower yield of quality cuts.

2.3.12. Wither height

Wither height (also known as shoulder height/height at shoulder) is the distance from the ground to the top of the scapula (De Boer et al., 1974) and is measured using a height stick more commonly used when measuring the height of horses (see figure 2.5 below). It is shown to be one of the measurements more commonly used, and is easily repeatable (Maiwashe et al., 2002) and accurate when assessing cattle morphometrics, although in some studies it is not shown as a great predictor of live weight. For example, Alderson (1999) found that it correlated poorly with live-weight (0.566) in White Park cattle and thus had limited value as an indicator or predictor of weight, especially when compared with other measurements such as hip width, which had a much stronger correlation with the weight measurement (0.861) and would therefore be a more accurate predictor of live weight.

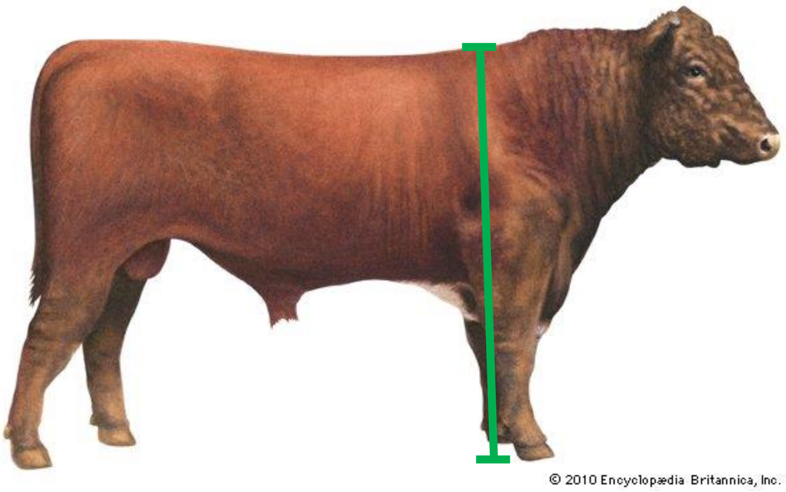


Figure 2.5: The Correct Position of the Height Stick for Measuring Wither Height in Cattle

Source: Adapted from Alonso et al., (2007); Encyclopaedia Britannica (2010)

There are some studies however which have demonstrated the relationship between wither height and conformation according to the EUROP classification scheme. In 2004, Coopman et al., found that Belgian Blue bulls which achieved a higher conformation class at slaughter were, on average, approximately 6cm taller than those achieving a lower classification. This greater height appears to help accommodate a greater muscle content within an animal, and it is those with better muscling that attain better carcase classes at slaughter. However, in contrast to this, it was found that taller animals of commercial crossbred breeds were highly correlated with less lean meat and fat in a carcase than the shorter, blockier ones, therefore making the shorter cattle more desirable from a beef production perspective (Black et al., 1938). Furthermore, it was found in 2002 by Maiwashe et al. that shoulder height correlated highly with body/back length, which could be extremely useful in assessing live cattle for slaughter as it could potentially mean that taller cattle are longer in the body and are therefore more (or less) likely to meet a desirable classification. It would also mean that should a similar correlating relationship be found, only one of these measurements would need to be taken forward into the statistical modelling process.

2.3.13. Wither width

Wither width (also known as shoulder width and in some cases, width of chest) is measured from the widest point across the shoulders with the correct way to measure wither width in cattle is shown in figure 2.6 below. Wither width was shown by Alderson in 1999 to be the least repeatable of all measurements, however it has been shown to vary slightly across different carcase conformation levels at slaughter. In 2004, Coopman et al., found a slight difference between the wither width of Belgian Blue cattle falling under two different conformation levels. Cattle that achieved an “S” classification had a wither width average of 69.9cm whereas those that classified as “E” achieved an average of 67cm. Although not a substantial difference, it does indicate that broader cattle may achieve a better carcase classification, which would make sense given that the more convex the animal, the greater muscle mass within, with animals having broader shoulders considered more desirable and having greater amounts of quality cuts of meat (Hemken, 2015).

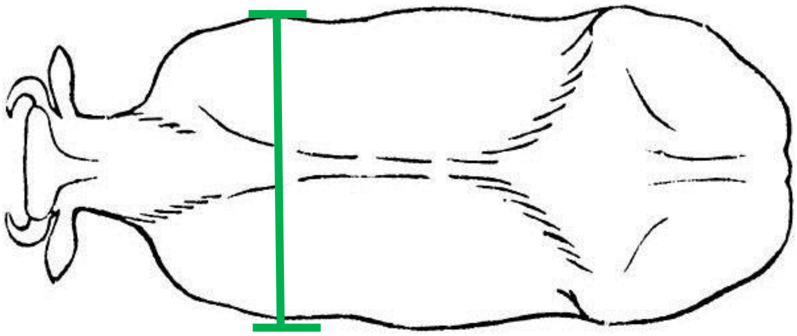


Figure 2.6: Top View Positioning of Tape Measure for Measuring Wither Width in Cattle

Source: Adapted from Allen (1865); Alderson (1999).

2.3.14. Pelvis height

Pelvis (or rump/hip) height is most accurately measured from the ground to the point of the tuber coxae (hook bone) with a measuring or height stick more commonly used for measuring height in horses (see figure 2.7 below) and has been found to be one of the more easy and repeatable of all measurements when undertaken in this manner (Alderson, 1999; Parish et al., 2012). Pelvis height is widely used to assess frame score in cattle and also for predicted progeny differences and is said to be directly related to the weight at slaughter at which cattle should meet prime grade (Parish et al., 2012), although this was according to the US system of beef carcase classification and not the EUROP grid. Kolkman et al. (2009) found that there was no significant difference between the pelvis heights of cattle culling out at either S or E classes according to the EUROP grid of carcase classification. However in 2004, Wall et al. found that pelvis height is a significant predictor of carcase yield ($P < 0.001$) although Alderson (1999) found that it was not necessarily a good indicator of weight in the live animal. In contrast to this, a more recent study found that significantly high correlations were found between live weight and height at pelvis and withers when combined (Przysucha et al., 2012), thus indicating that pelvis height could relate to overall carcase weight after all and therefore is potentially linked to final carcase classification.

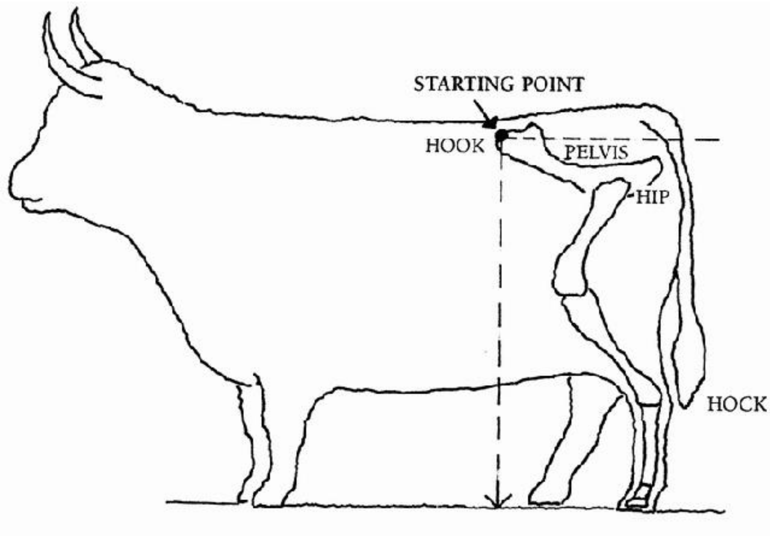


Figure 2.7: Measuring Pelvis Height in Cattle

Source: Ruatiti Highland Fold (2012)

2.3.15. Pelvis width

Pelvis width (also known as hip width) is measured across the back from one hip/hook bone (tuber coxae) to the other (see figure 2.8) and has been shown to be the preferred single measurement for the physical evaluation in regards to body type and function of individual animals (Alderson, 1999). A wider pelvis has always been most desirable particularly in regards to female cattle as this reduces the risk of dystocia and caesarean during calving, however a wider pelvis should not compromise the conformation or size of the animal (Kolkman et al., 2009). Interestingly. Kolkman et al. (2009) did not find significant differences between the pelvis widths of cattle culling out at either S or E classes according to the EUROP grid of classification, which could indicate that the rear width of an animal doesn't necessarily relate to carcase conformation past a certain class. It could also mean that pelvis width is more directly related to fat class and percentage content rather than the conformation of a carcase.

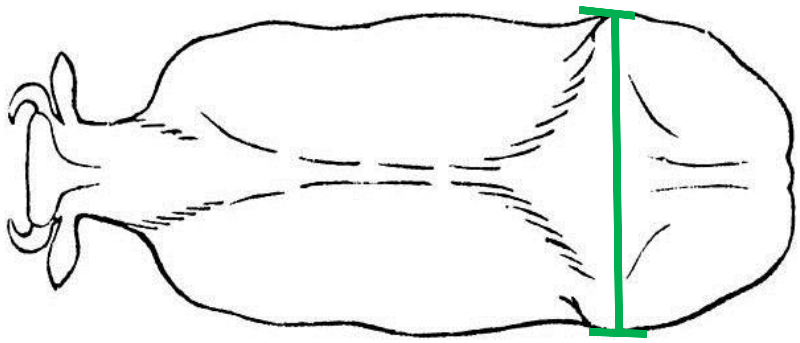


Figure 2.8: Top View Positioning of Tape Measure for Measuring Pelvis Width in Cattle

Source: Source: Adapted from Allen (1865); Alderson (1999).

2.3.16. Rump width

Rump width (also known as thighs width) is measured as the width from one side of the rear to the other, at the widest and broadest point of the hindquarters (demonstrated in figure 2.9 below) (Coopman et al., 2004; Alonso et al., 2013).

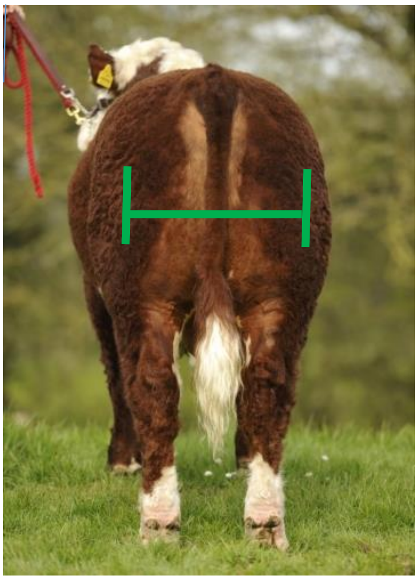


Figure 2.9: Measuring Rump Width in Cattle

Source: Adapted from Coopman et al., (2004); Alonso et al., (2013); Munster Cattle Breeding Group (2016)

In a study by Coopman et al. (2004), average rump width in the live animal was shown to vary depending on the conformation class the carcase was assigned. They found that the average rump width for Belgian Blue bulls which culled out at the S conformation was 66cm wide whereas those culling out at the lower E conformation had an average rump width of 63.8cm. Rump width has always been of interest within both the beef and dairy industries as narrower rumps and pelvises are indicative of dystocia and reduced fertility and so are therefore deemed less desirable (Shapiro and Swanson, 1991; Wall et al., 2005). In cattle, wider rumps are generally seen as a good indicator of nutritional efficiency with a greater capacity to store meat and fat within the body (Ruechel, 2006) and are subsequently linked with better conformation. Alongside this, the EU community scale for carcase classification (which describes carcases in terms of the EUROP classification grid) again points to the more convex, wider animals achieving greater conformation at slaughter, with it stating that wide, more convex and rounded animals are most likely to achieve the E and U conformations (Lazzaroni and Biagini, 2008). Figure 2.10 below demonstrates how as the rump width of cattle increases, so does the conformation level according to the EUROP system; thus adding to the theory that increasing rump width increases the likelihood of cattle achieving a desirable conformation post-slaughter.

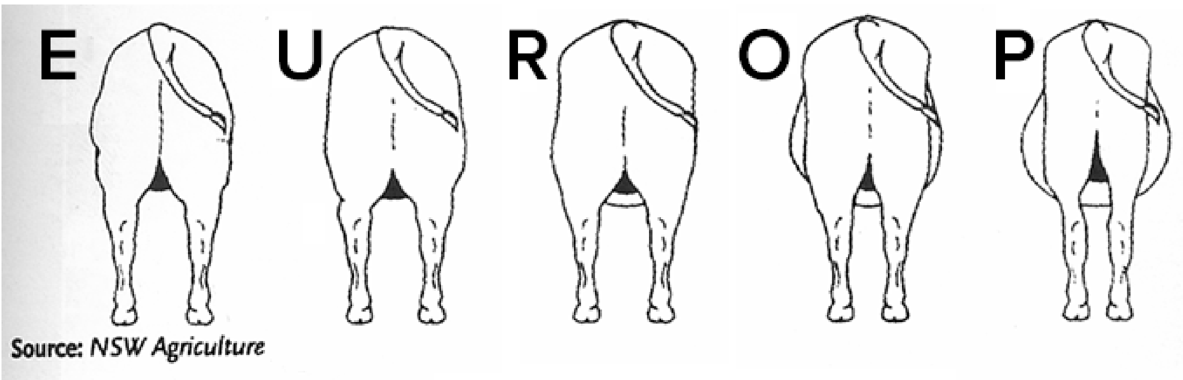


Figure 2.10. Linking Rump Width to Conformation Level

Source: New South Wales: Department of Primary Industruies (2015)

This means that emphasis is now placed on breeding cattle with wider rumps, which could be emphasised further should a wider rump within a specific width measurement be shown to have a direct, significant relationship with carcase classification at slaughter.

2.3.17. Rump length

It has been found that there are differences between various studies as to what the term “rump length” actually refers to when taking linear measurements from cattle, which can make it hard to decide on the correct positioning and taking of the measurement. For example, in 1999 Alderson stated that rump length was measured from the tuber coxae (hip or hook bone) to the tuber ischii (pin bones). In slight contrast to this, Hadiuzzaman et al. (2010) measured rump length as the distance between the base of the tail and the hip bone, with “thurl width” as the name given to what the Alderson study described as rump length. However, in a study by Alonso et al. (2007), they noted a measurement “L6” which originated from the P8 site down to where the flank of the animal and the hind limb meet (see figure 2.11 below) and although this measurement could not be used in their study due to photographic angles, it appears to take into account the convexity of the round. It is therefore of great interest to see if there is a relationship between this L6 (hereby known as rump length) measurement and other rump measurements (width/round profile) that directly relate to carcase classification as it is a longstanding belief of the more traditional farmers that a larger round is most desirable and achieves better classification.

Figure 2.11: Measuring Rump Length in Cattle

Source: Adapted from Alonso et al. (2007); Encyclopaedia Britannica (2010)

2.3.18. Round profile

Round profile is said to be highly important when assessing beef cattle for suitability for slaughter as it gives a clear indication of muscular development within the animal, which has then been shown to have a direct relationship with carcase value and can therefore be used to aid live animal selection (Alonso et al., 2007; Alonso et al., 2013). “Round profile” is the term given to assessing the curvature (muscularity) of the buttocks in cattle, with the curvier, more muscular cattle having larger round profiles (Daelemans et al., 2008; Mira et al., 2009). In a study in 2008 by Alonso et al., round profile was assessed by visual appraisal on a scale of 1-5 points according to how convex the round of an animal appeared to be; with 1 being assigned to those animals which were typically extreme dairy cattle in shape and 5 being extremely muscled and convex. Figure 2.12 below shows how the assessment and potential site of measurement of the round profile in cattle of varying levels of convexity works, by measuring from the anal fold underneath the tail head to halfway down the tibia and fibula, at the point where the round meets the rear limb. However, assessing cattle using visual appraisal alone is notoriously subjective, unreliable and unrepeatable (Alonso et al., 2007; Daelemans et al., 2008) and so by utilising an actual numerical measurement and tool (such as a tape measure) to accurately measure the round of the animal could potentially prove to be more reliable and useful in scientific research.

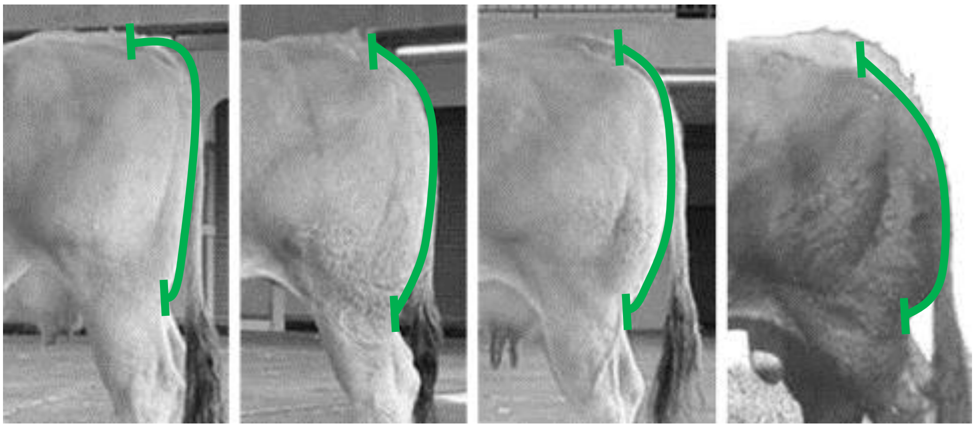


Figure 2.12: Measuring Round Profile in Beef Cattle

Source: Adapted from Alonso et al. (2013).

2.4. CONCLUSION

It is through reviewing past literature on the development of beef carcase classification and the aforementioned fifteen different ultrasonic and fat measurements that decisions on the best and most practical ways to obtain these readings on-farm can be made. As subjectivity is such an important factor within the UK beef sector in regards to live-animal assessment, enabling the use of a more objective means of assessing cattle prior to slaughter is of great benefit to both farmers and the overall industry in terms of economics, wastage and receiving the best prices for carcases. However, improving objectivity in pre-slaughter assessment of live cattle also needs to be achieved through simplistic, cheap and easily repeatable means, in order for farmers on all levels and scales of farms to be able to utilise these methods in the everyday working environment. After looking at the methods used for obtaining all fifteen of the measurements above, it can be concluded that the basic tools needed for objective pre-slaughter assessment using all of these measurements include an ultrasonic fat depth reader, a tape measure, a height stick and skinfold calipers, in addition to a built-in weigh scale within the cattle crush itself. With the aim of this work being to have a minimal amount of live animal measurements as indicators of final carcase classification, these five basic tools should be able to go on and help farmers to assess their cattle for suitability for slaughter in order to achieve the most desirable carcase classifications and receive optimum payment for their animals.

CHAPTER 3: CURRENT METHODS USED BY ENGLISH FARMERS TO DETERMINE PRIME SLAUGHTER CONDITION IN COMMERCIAL BEEF CATTLE

3.1. INTRODUCTION

The English Beef and Lamb Executive (EBLEX) state that the optimum carcase classification needed for the UK beef industry, and in particular for supermarket sales is the R4L classification, which is a “good” conformation (R) and the lower end of the level 4 for fat level (4L); however other premium classes for the UK also include a range of E, U, 3 and 4L classifications, depending on the market specification. (EBLEX 2012a). EBLEX (2012e) report that 51% of cattle slaughtered in the year of 2011 fell outside the UK premium classifications through being too fat, too lean, poorly conformed or combinations thereof and it is seen even from today that this trend continues. The current payment system to farmers is dependent on the grade achieved by the carcase, therefore it is crucial that beef producers ensure as many animals as possible meet the R4L or other UK premium grades as significant negative financial and economic effects are observed when sending overly fat or poorly conformed animals to slaughter (Lambe et al., 2010).

In order to understand why so many animals are failing to meet the grade, an assessment of the way farmers select their animals for slaughter needs to be carried out to see what methods and assessment aids, if any, are currently being used in the selection process. Recent published literature (Alonso et al., 2007; Lambe et al., 2010; Craigie et al., 2012) suggests that current live animal selection methods used by farmers are primarily based on weight recording or visual and manual assessments, such as visual assessment of conformation and manual handling of specific points on the animal (for example, the loin, rump and brisket regions). Furthermore Alonso et al. (2007) suggests that these methods, whether carried out by farmers or trained officials, are subjective and there is wide variation between assessors, which could go some way towards explaining why so many animals are not culling out at desirable classifications. In order to try and reverse this trend and provide some objectivity in pre-slaughter assessment of beef cattle, a number of aids for assessment of live cattle have become available in recent years. The EBLEX Better Returns Programme (BRP) and Live-to-Dead days held at abattoirs across the UK are examples of these and theoretically enhance farmer's knowledge of what to look for and what to avoid when assessing and selecting their own animals for slaughter on-farm (National Farmers Union, 2012). However, even with the availability of these tools, it is currently unknown as to what percentage of UK beef farmers actually utilise these facilities, and if they do, to what extent they actually help in ensuring cattle reach desired classification. Therefore the objectives of this questionnaire survey were to determine what methods (if any) of pre-slaughter assessment UK beef farmers are currently utilising to determine suitability of their beef cattle for slaughter, in respect of age and education level of the person undertaking the assessments. These methods include visual, manual and weight-inspection (and combinations thereof) of live animals on-farm. Further analysis then goes on to examine the usage and efficacy of recommended selection tools already provided, such as the Better Returns Programme (BRP) and Live to Dead (LtD) days in relation to cattle meeting optimum classification at slaughter.

3.2. MATERIALS AND METHODS

3.2.1. Sample selection and questionnaire design

A voluntary postal survey of 200 randomly selected beef producers across England was undertaken with the assistance of the English Beef and Lamb Executive (EBLEX), who sent out the survey to a randomised sample of English beef famers, selected through the use of a random number generator; a full sample of the questionnaire can be seen in Appendix B. A postal survey was chosen over an online-based resource as research by Nulty (2008) suggests that the response rate to online surveys is much lower than the response rate to paper-based surveys. It was also noted that many of the elder producers or smaller farms may not have access to online facilities or may not necessarily be as computer-literate. The comprehensive questionnaire was designed to take no longer than 10 minutes to complete and consisted of four distinct sections. Section A was designed to give a background to the producer themselves, giving information on age and education level. Section B outlined the type of production system used and the specific breeds of cattle kept. Section C looked at pre-slaughter methods of assessment used and what specific points on the animal were taken into consideration, as well as desired and actual classification at slaughter. Finally, section D analysed the use of current available assessment aids (BRP and LtD days) and how the producers rated their usefulness. Basic questions were of the ‘tick the box’ and Likert scale variety and where bias was a possible issue or direct reporting of figures (for example, number of cattle reaching premium grades) was required, questions were open ended.

3.2.2. Data analysis

Data from the survey was analysed using the IBM SPSS® Statistics software, version 22. Pearson's Chi-Square statistical test for comparisons between categorical factors was utilised and where assumptions of asymptomatic standard statistical methods were not met, these were corrected for through the Fisher's Exact Test. Further analysis of use of the BRP and attendance to the LtD days was conducted using GenStat 13th Edition and Logistical Regression Modelling for binomial proportions (n successes for premium grades) with binary explanatory variables for utilisation of BRP and attendance at Live to Dead events (0 = no, 1 = yes). The model was stipulated thus:

$$\log(y) = \beta_0 + BRP\ x + LtD\ x + e$$

Where BRP and LtD are the binary variables.

3.3. RESULTS

3.3.1. Sections A and B: Description of study population

A total of 47 usable responses were received which represented a response rate of 23.5%.

The majority of respondents (73%) had a total of 200 or less beef cattle on the farm with 51% having 100 cattle or less. A further 13% had total cattle numbers of over 400, with the remainder being between 201 and 400 cattle. Twenty five per cent of respondents operated 'mainly cereal' based systems finishing between 12 and 18 months of age with the just over half of the farms (51%) being combination silage/grazed systems finishing cattle between 18 and 24 months. The remainder were finishing on 'primarily grazed' or 'primarily silage' systems finishing at any time up to 32 months of age and in the case of one farm over 32 months of age.

Out of all the farmers surveyed, 77% were owner occupiers, 17% Tenant Farmers, the remainder being Farm Managers. The majority of respondents (85%) were age 40 or over, with 38% being over 60 years of age. Regarding education levels, just over a third of the sample population (36%) left formal education at the age of 16, meaning that the highest level of education achieved by a large proportion number of the sample was School only. Only 13% of respondents continued through to university level education, the remainder (51%) achieving Further Education or Higher National Diploma (HND) level. Figure 3.1 illustrates education levels in relation to age of respondents.

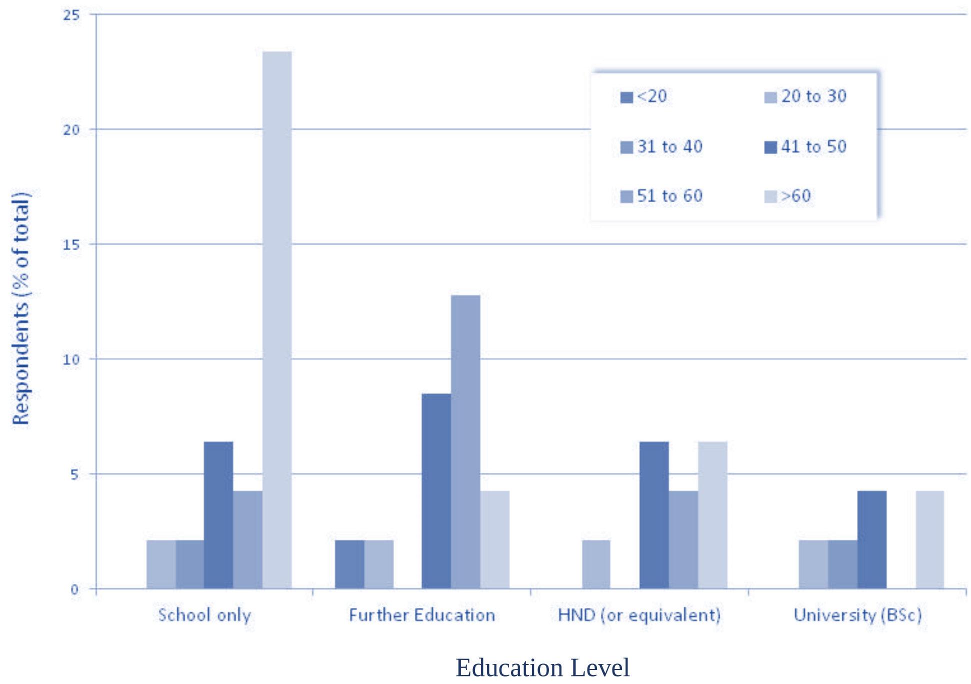


Figure 3.1: Education Levels in Relation to Age of Farmers Surveyed

It can be observed from Figure 3.1 above that within the total sample population the highest number were in the over 60 age group leaving school at age 16 or under, followed by the 41 to 50 age category educated to FE level.

3.3.2. Section C: Methods of pre-slaughter selection

When analysing the use of weight recording as a tool for determining the fitness of an animal for slaughter, it was found that those farmers under the age of 50 used this method significantly more than those farmers over the age of 50 ($P = 0.004$). Out of the 28 respondents aged 50 or over, only five used weight recording as a means of assessment, but all in conjunction with other methods: One in conjunction with visual assessment, one in conjunction with manual handling and three in conjunction with both visual assessment and manual handling. For respondents below the age of 50, eleven from a total of 19 used this form of assessment, three in conjunction with visual assessment and eight in conjunction with both visual assessment and manual handling. No farmers in this study used weight as a stand-alone means of determining readiness for slaughter in beef cattle. Furthermore, no significant differences were observed regarding levels of education and use of weight recording when analysed for both school only and university level education ($P = 0.753$ and $P = 0.071$, respectively).

Looking at the use of visual assessments either as a stand-alone assessment or in conjunction with other assessment methods, it was found that neither age nor education level had any significant effect on the use of this method ($P > 0.05$). Almost all farmers (97.8%) used visual assessments as a tool for pre-slaughter assessment and when assessing cattle, a high proportion of farmers (32%) examined the overall shape of the animal alone. For those that scrutinised specific features and areas of the animal, particular attention was paid to the brisket, rump and loin regions as indicators of peak slaughter condition.

Age and education level once again had no significant effect on the usage of manual handling as a means for pre-slaughter assessment (P > 0.05) with only 22 farmers (46.8%) actually utilised this method of live-animal assessment. However, within the respondents that actually did use manual handling (either as the only tool of assessment, or in conjunction with others), the areas of particular interest included both the rib area and handling of the transverse processes (loin). Interestingly, it was found that farmers over the age of 40 tended to be more likely to handle the ribs of the animal during manual assessments than younger farmers, although this was not quite significant (P = 0.059). In contrast to visual analysis where overall body shape was the primary focus, only 13.6% of farmers who used manual handling as an assessment tool actually assessed the animal as a whole, with the remainder preferring to focus on more specific regions of the body.

Analysis of respondents' desire to attain specific classifications across the EUROP grid revealed that age does have a significant effect on the class desired, and that those who wanted to meet the R4L category were much more likely and able to do so than those who desired any other class on the EUROP grid. R4L was desired because it has good returns and the farmers receive a premium for meeting this particular classification. The classes that farmers desired (aside from R4L) included U conformation as these were more suitable for selling to butchers and for export purposes. Younger farmers (under the age of 40) significantly wanted to meet the R4L classification over and above all other classifications when sending their cattle to the abattoir, whereas older farmers were more happy with meeting other UK premium classes, such as R3 and U+4L (P = 0.029). Unlike age, education level had no role to play in what classification beef producers desired. Figure 3.2 below illustrates the number of animals reaching the stated desired classification for respondents with a large group of respondents (30%) stating that 90% or above of cattle sent for slaughter reached their desired classes, however this figure may be subject to bias as farmers are not likely to admit that a large proportion of their cattle are not meeting desired class. In contrast to this however, over a quarter of respondents (26%) stated that less than 70% or of their animals actually met their desired classes. There were no statistical significances were found in respect of age and education level and the number of cattle reaching the farmers' desired class.

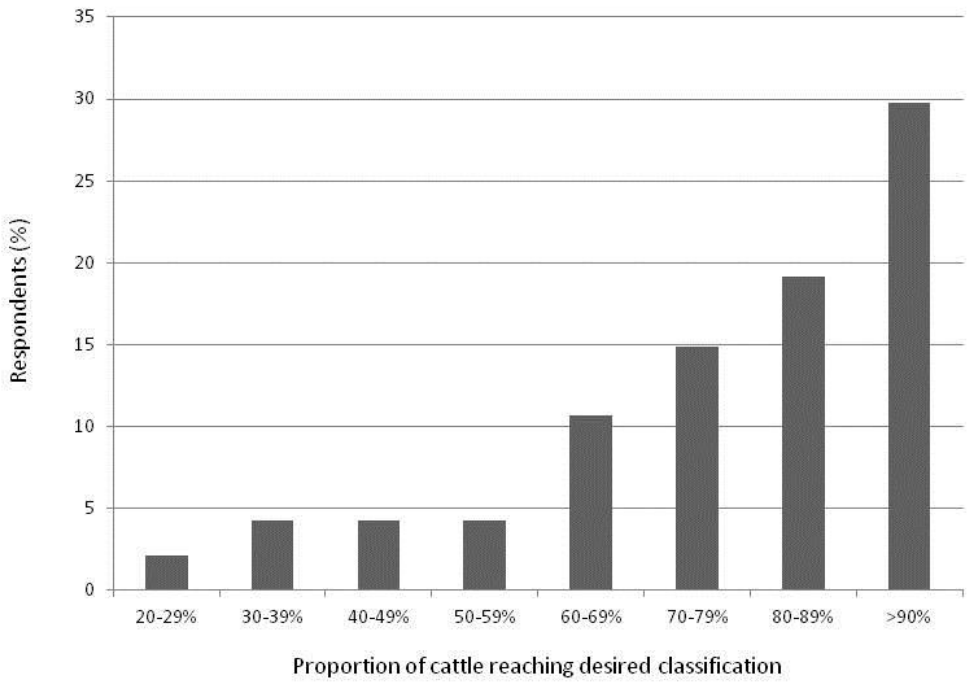


Figure 3.2: Percentage of Cattle Meeting Desired Classification at Slaughter

3.3.3. Section D: Use of current assessment aids

In regards to awareness and use of the BRP, 96% of respondents reported that they were aware of the BRP with the two respondents who stated they were unaware of it being in the over 60 age category. It was found that farmers under the age of 50 are significantly more likely to make use of the tools provided by the BRP than farmers over the age of 50 (P = 0.028). Interestingly, no significance differences were observed when comparing the highest (university) and lowest (school only) education levels with use of the BRP (P = 0.908 and P = 0.097, respectively). Just over half of all farmers surveyed (51%) stated that although they were fully aware of the BRP, they did not however use the BRP to help them assess their cattle prior to slaughter with the main reason for this lack of use being that it was *'not necessary as experience alone counts'*. When comparing those who utilised the BRP to those who chose not to, there was no difference between the likelihood of cattle meeting a UK premium class on the EUROP grid (P = 0.592).

Attendance at Live to Dead Day

A total of 38% of all respondents to the survey had attended a Live to Dead event. Those that hadn't attended cited that they *had not had the opportunity; it would not be beneficial; was too far to travel; too expensive or just hadn't got time to spare.* No significant differences in attendance among farmers over and under 50 years in age was found (P = 0.658), furthermore no significance in attendance was recorded between those with a university education and those without (P = 0.185).

Influence of BRP and Live to Dead days on cattle reaching desired classification

In order to establish the usefulness of either the BRP and/or Live to Dead days either as singular entities or as a pair, a logistic regression analysis was performed to see the effect of using these aids on the number of cattle meeting the desired classification(s). The outcome of the model is displayed in table 3.1 below:

Table 3.1: Outcome of the Logistic Regression Model on the Effectiveness of Current Assessment Aids

Parameter	B-estimate	Significance	Odds Ratio (antilog)
Use BRP	-0.6966	<.001	0.4983
Attend LtD	0.7613	<.001	2.141
BRP and LtD	0.4859	<.001	1.626

The results from Table 3.1 show that using the Better Returns Programme and attending a Live to Dead day were both statistically significant variables. However, in this case the odds ratio for use of the BRP alone is 0.5, thus showing a decrease in the percentage of cattle attaining the desired class in those farms using the BRP as a sole means of pre-slaughter assessment aid. In contrast to this, attendance to a LtD day alone showed a significant increase in the percentage of cattle attaining the desired class with an odds ratio of 2.14.

Analysis was then carried out for those farmers who stated that they used both the BRP and attended a LtD day, to see the impact that this would have on cattle reaching desired classifications when compared to using only one of the two assessment aids. The results from this analysis was also shown to be significant (P<0.001), again showing an increase in the percentage of cattle reaching desired classes. However, the odds ratio of 1.63 therefore indicates that use of both assessment aids together was not as successful as attending a Live to Dead day alone, but was more successful than utilising the BRP only.

3.4. DISCUSSION

3.4.1. Description of the study population

The sample selection method for this research was totally randomised using a random number generator, meaning that a range of beef farms from across England was utilised for the purposes of this survey, although this could mean that the sample population may not necessarily be representative of the general population. However, when looking at the age of farmers partaking in the survey, it is noted that the majority of farmers were of the elder generation (>50). This is representative of the general population in that the average age of a farmer is 58 with 58% of farmers being over the age of 55 (Eurostat, 2013; McKenzie, 2012).

Although the response rate of 23.5% appears relatively low, research still suggests that physical paper-based surveys (such as this one) continue to attain a higher response rate (sometimes twice as high) than those of the online variety (Dommeyer et al. 2004; Ballantyne, 2005) and that farmers prefer physical based-work to computerised office time (Alvarez and Nuthall, 2006). This choice of method was taken into particular consideration when looking at the target population, with some farmers not necessarily being computer-literate and able to complete an online survey. Although the response rates were relatively low overall and the survey was carried out in a single mail shot owing to resource constraints, the age distribution of farmers was actually found to be representative of that of UK agriculture as a whole. The majority of beef finishing systems were represented with a mixture of both cattle types and slaughter ages.

3.4.2. Methods of pre-slaughter selection

From the questionnaire study, it was found that weight alone is not a valid means of assessing readiness for slaughter in live cattle and was always used alongside manual handling and/or visual assessments when selecting cattle for slaughter. This therefore means that it needs to continue to be used in conjunction with other pre-slaughter assessment methods. However, a limitation to this part of the study was that it was not clear how many farmers had the means to weigh animals and yet chose not to; as well as finding out their reasons for or for not using weight as a means of live animal assessment. Reasons for this lack of use/use as a sole means of live animal assessment could include inaccuracies and daily fluctuations in weight caused by gut-fill of the animal impacting the reading, making it appear heavier (and therefore more suitable for slaughter) than it actually is, with Wythes (2012) finding that gut fill can account for up to 22% of the total weight of an animal. Furthermore, weight alone also does not take into account musculature or level of fatness of the animal – a very heavily muscled animal may meet desired weight faster, but too little fat is not favourable amongst the average UK supermarket. The EBLEX BRP does not really emphasise weighing as a vital tool in live animal assessment and this was reflected in the study with it being the least utilised of the three assessment methods.

The EBLEX BRP literature encourages visual assessment of the overall animal and manual handling of specific points such as the loin and ribs (EBLEX, 2007). The research presented here concurs with this and shows that overall visual assessment of the entire animal is the method most used by beef producers when selecting animals for slaughter. In contrast to the

BRP recommendations however, manual handling plays a less significant role in pre-slaughter assessment with just under half of the respondents undertaking any form of this, either as a stand-alone assessment or in conjunction with other assessment methods. The data also suggests that the areas for manual handling depended on individual farmers' preferences with no set pattern shown across the sample population, thus demonstrating that they are not using the BRP to its full potential or following the guidelines. Areas of particular interest within the study included the ribs and loin combined, however other responses included, ribs only, tail head, rump only and further combinations thereof. This lack of uniformity in handling practices indicates that farmers are not certain of the most useful areas to manually assess in their cattle and could therefore be a further reason as to why unready and unfit cattle are sent to slaughter.

3.4.3. Use of current assessment aids

It was found from the study that farmers over the age of 50 were significantly less likely to use the BRP, coupled with over half the sample feeling that it was unnecessary as it was frequently stated that experience alone was what mattered. This goes along with the theory that older farmers are more traditionalist and do not always accept and utilise new ideas all that well, even if they are proven to be financially beneficial (Amudavi et al., 2009). In conjunction with this, older farmers may be less willing or able to use the computer programmes, which concurs with research by Alvarez and Nuthall (2006), who also found that farmers over the age of 50 are much less likely to utilise computer software programmes than those of a younger age. Interestingly however, it was found that farmers using materials provided through the BRP do not always have greater success in ensuring their cattle meet a UK premium classification. This may well be owing to the different perceptions of what a suitable finished animal should look like, i.e. the type advocated by the BRP program versus a more traditional type handed down from father to son, causing confusion among what to look for in a desirable beef animal and thus reducing the amount of cattle that actually meet desired classification. According to the results from the logistic regression analysis, using the BRP alone seems to result in a decrease in the percentage of cattle attaining desired classification, potentially explained by the aforementioned confusion, however when used in conjunction with the Live-to-Dead day there is a significant increase in the percentage of cattle reaching the desired class than when neither aid is used. It was also found that the most successful means of ensuring cattle reach the desired classification is the attending of a Live-to-Dead day alone. Reasons for this could be that actually witnessing and handling a live animal first, then as a carcass, with the focus on loin and rib regions (as opposed to more "traditional" areas such as the rump) allow farmers to build up a better interpretation of what to look for in their own animals. There is evidence that shows that farmers are experiential learners and rely on first-hand experience to learn new techniques (Franz et al., 2010). This means that they learn better by physically doing tasks rather than, for example, reading about them or watching a computer simulation. This would therefore go some way to explaining why the LtD days prove to be so effective in helping ensure cattle which are suitable and suitable for slaughter are selected. Following on from this, with nearly 40% of the total farming population over 60 years of age, attending an abattoir may be viewed by the older generation farmers as a more useful method of pre-slaughter training as opposed to reading through manuals or use of computer simulations.

3.5. CONCLUSION

This research suggests that do not currently use reliable methods to select cattle for slaughter. Future new assessment aids should focus on incorporating and combining more traditional methods of live-animal assessment (such as weight recording and handling of the ribs) along with newer, more objective methods, as well as continued use of Live-to-Dead training schemes in order to create a compromise between more traditional farmers and those newer to the industry. Learning by doing (experiential learning) appears to be successful within the UK beef industry due to those farmers attending LtD days being more likely to select cattle which will meet desired classes at slaughter and therefore it is suggested that more emphasis should continue to be placed on attending LtD days and actual physical assessment of live animals, with further research needed into the success of LtD days in improving farmers' targets for number of cattle reaching the desired classification. It appears from this study that any potential new methods of assessing live animals need to have a more physical, objective basis that farmers can easily replicate, rather than a theoretical or computer-based approach as these seem to be the best methods to ensure desired classification at slaughter. Following on from these findings, the next stage of this research was to test all available methods used to assess and select cattle for slaughter and then reduce these to a manageable number in order to try and promote farmer uptake in using them to assess their own cattle.

CHAPTER 4: MATERIALS AND METHODS FOR DATA COLLECTION

4.1. INTRODUCTION

The eventual aim of this research project was to create a model for predicting whether or not cattle will meet a desired UK premium carcase classification. In order to achieve this, two main studies were carried out. Firstly, the fifteen measurements described in chapter 2 were taken from a group of 71 commercial beef cattle prior to slaughter, in order to see whether a selection of these measurements could be used to help predict whether or not the cattle would meet a UK premium carcase classification. Secondly, the selected measurements were further trialled on 120 prime commercial beef cattle, reducing the group of measurements down further, while factoring in breed, in order to predict carcase outcome. The materials and methods used in these two studies are detailed below:

4.2. SUBJECTS AND MANAGEMENT

For the purposes of the two live-animal studies, between the years of 2011 and 2015, a total of seventy one commercial crossbred beef cattle were used for the initial study. In the first year of the trial (2011/2012), 17 heifers were used as a basic pilot study to check management and measurement procedures and feasibility of the study. In the following years, 3 more batches of heifers were used, with the final batch (2014/2015) consisting of steers rather than heifers. All cattle used in this study were three-way crosses with terminal sire breeds consisting of the Aberdeen Angus, Limousin, Simmental and Belgian Blue. Cattle were obtained from various suckler farms between September and November at approximately 8-9 months old and were housed over winter in the cattle shed at Sturgeon's

Farm, Writtle College, with continuous access to a small outdoor yard. Cattle were fed *ad lib* silage as well as supplementary concentrates (Duffields Beef Finisher Pellets, (12.5 MJ/kg ME, 16% CP) see appendix A) at 2kg per head per day during winter housing. During the summer period (April-September), cattle were put out to graze. Supplementary concentrates were provided during extreme weather when grass and grazing condition was poor. Cattle were then housed during the finishing period, fed concentrates (see appendix I) and *ad lib* silage from September to March. Cattle then went to the abattoir in batches of 3 to 5 animals, aged between 22-26 months old when they weighed between 550 and 650kg and were visually assessed to be suitable for slaughter.

For the second live-animal study, a total of 120 commercial crossbred beef cattle were obtained from a beef finishing farm in North Yorkshire. This group of cattle consisted of 48 Limousin (and crosses), 19 Aberdeen Angus (and crosses), 34 Charolais (and crosses), 10 Simmental (and crosses) and 9 "other" breeds (consisting mainly British Short Horn and Belgian Blue crosses), all between 24 and 36 months of age. This sample was broken down into 80 steers and 40 heifers. Cattle were housed indoors throughout the finishing period, fed a high concentrate diet and had continuous access to silage. Cattle were sent to the abattoir in groups of 40 when they met a target weight of a minimum of 600kg and were visually assessed to be suitable for slaughter.

4.3. LIVE-ANIMAL MEASURING EQUIPMENT

All of the cattle used in the first study were visually inspected by the author and weighed weekly with the assistance of undergraduate dissertation students in the finishing period to determine readiness for slaughter. This also allowed for animals to become accustomed to the handling facility and used to being handled in order to make the final measuring process as easy and as least stressful for the cattle as possible, as it has been shown in a study by Turner et al. (2011) that a calm response in a cattle crush handling facility is associated with a higher average daily gain during the fattening period (P = 0.05), with this being important in the study for ensuring that cattle finished in a desired time frame. 24 hours prior to being sent to the abattoir, cattle were put through the handling system for a final time and restrained in the crush while being weighed and the other 14 measurements were taken by the researcher. This occurred in the morning, before they had been fed their morning concentrates in order to combat the gut-fill effect so that live-weight was as accurate as possible. Ear tag identification numbers of all of the animals were recorded in order to link carcase classification to the individual set of measurements taken off each animal once abattoir feedback was obtained. Measuring equipment was all supplied by Writtle University College Science Department and Sturgeon's Farm

Cattle used in the second live-animal study were visually inspected and weighed weekly by the finishing farm in order to determine readiness and suitability for slaughter. This meant that the animals were used to the handling facility, again to reduce stress and keep average daily gain as high as possible for a faster finish (Turner et al., 2011). Once a group of 40 cattle was deemed suitable for slaughter, cattle were then put through the handling facility 24 hours in advance of being sent to the abattoir and five measurements were taken off each individual once they had been secured within the cattle crush. Ear tag identification number was recorded in order to link final carcase classification to each individual set of measurements once abattoir feedback was obtained. Measuring equipment was all supplied by Writtle University College Science Department. The details of all the measurements taken from the live animals in the studies are shown below:

4.3.1. Weight recording

The crush used to restrain the animals in study one had in-built scales which are primarily used to monitor weight gain during both the growing and finishing period, and were previously used by farm staff to determine readiness for slaughter. The weight of the individual animals was recorded in kilograms once the cattle were stationary inside the crush and was rounded to the nearest kilogram. To counteract any anomalies all four feet of the animal were ensured to be positioned on the floor and that the animal remained stationary and was not leaning or kneeling inside the device while the weight was being taken. If the animal moved during the weighing process, the weight was taken again once it had settled. Once weight had been recorded, the animal’s unique ear tag identification number was also read and recorded for future reference.

4.3.2. Morphometric measurements

Morphometric measurements (wither/pelvis/rump width, back/rump length, heart girth and round profile) were all taken using a standard flexible, retractable 300cm tape measure (see plate 4.1). Further measurements of wither and pelvis height were taken using an equine height stick (plate 4.2) with a built-in spirit level to help ensure accurate readings. Measurements were rounded to the nearest centimetre.

Plate 4.1: Tape Measure used for Measuring Cattle

Source: Pelenna Patchworks (2016).

4.3.3. Wither/pelvis/rump width

The width of withers was measured across the widest point of the shoulders, as described by Alderson (1999). During the taking of this measurement, cattle had to be stationary and could not be leaning or kneeling within the crush as this would give an inaccurate reading. Pelvis width was measured in a similar fashion with the measurement taken from the point of one hook bone (tuber coxae) to the other. Again, cattle had to be stationary and not leaning/kneeling during the measuring process and care was taken to avoid getting kicked. Rump width was measured from one side of the rump to the other, taking into account the widest, broadest area seen from behind. The tape measure was positioned over the tail during the taking of this measurement.

4.3.4. Back and rump length

Back length was taken using a tape measure positioned at the dip in vertebrae between the centre point of the shoulder blades (withers) (as mentioned in Sulieman et al., 1990 and Sandford et al., 1982) and extended back across the loin, following the natural spine to the second caudal vertebrae just in front of the tail head. The tape measure was not pulled tight, but laid across the back of the animal in order to follow the natural spine and was checked to ensure there were no twists which could lead to an inaccurate reading. In longer cattle, assistance was needed from an undergraduate student to hold one end of the tape measure at the centre point shoulder blades whilst it was extended down the back. Cattle had to be standing and stationary during this process. Rump length was measured based on the study by Alonso et al. (2007) in which the measurement was taken from the P8 point down to the meeting point of the flank and the hind limb in order to objectively assess the convexity of the round.

4.3.5. Heart girth

Heart girth was measured by positioning the tape measure around the chest of the animal, just behind the forelimbs, centimetre-side up, as seen in Wood et al. (2015). Care was taken to avoid injury when retrieving the tape measure from the other side of the animal by using a hooked stick to snare the tape measure and bring it underneath the chest, out of reach of the hooves. The tape measure was then secured around the circumference of the chest and a reading taken, ensuring that the researcher's fingers were not in-between the animal and the tape measure, or that the tape measure was twisted at any point as this would create an inaccurate reading. If the animal vocalised during the reading, the tape measure was relaxed and the reading attempted again once it was settled as the act of vocalisation inflates the chest cavity and causes inaccuracy. The reading was only taken once the animal was calm and stationary.

4.3.6. Round profile

Round profile was measured from the anal fold where the tail joins the rump, round to halfway down the tibia and fibula, at the point where the round meets the hind limb, as displayed and described in the study by Alonso et al. (2013). The tape measure was ensured to be flat against the round, following the natural curve and the measurement was only taken once the animal was stationary, not leaning and with both rear feet positioned directly beneath it.

4.3.7. Wither and pelvis height

Wither height and pelvis height were measured using a height stick and the arm of the stick was positioned on the top of the scapula (as described in de Boer et al., 1974) ensuring that the arm was straight using the spirit level as a guide. The reading was then taken and rounded to the nearest centimetre once the animal was stationary and the fore limb positioned directly beneath the shoulder to ensure accuracy. Pelvis height was taken in a similar manner, again ensuring the arm was level and that the hind limb was positioned directly beneath the animal. Pelvis height was measured from the ground up to the top of the tuber coxae (hook bone), as seen in Parish et al. (2012) and Alderson (1999).

Plate 4.2: Height Stick used for Measuring Cattle

Source: Horse.com (2016).

4.3.8. Ultrasonic fat readings

Ultrasonic fat readings consist of the P8 fat point, 10^{th} rib fat point and 12^{th} rib fat point readings and were measured using the Renco Lean-Meater, Series 12, which can measure skin and fat thickness (see plate 4.3 below).

Plate 4.3: The Renco Lean-Meater used for Measuring Fat Depth in Cattle

Source: Renco Corporation (2009).

The P8 fat point was identified as the mid-point on the rump between the tuber ischii and tuber coxae. Once this position was identified, the probe was turned on and a small amount of lubricant was applied to the rump. The probe was then placed on the area in small, circular motions with the application of more lubricant if necessary in order to obtain an accurate reading. A reading was considered true once the probe settled on a specific fat depth reading. The 10th rib fat point was located by counting four ribs in from the most posterior 13th rib (inclusively) and approximately 18 centimetres down from the spine. The 12th rib was located as the second rib in from the rear and again, approximately 18 centimetres down from the spine (Bass, 1981; Cabassi, 1990). The same procedure was the followed as for obtaining the P8 fat point reading, ensuring the cow was stationary and not fidgeting as this could invalidate the reading. This piece of equipment was selected as it is relatively cheap (approximately £500) and relatively simple to use in comparison with other pieces of kit. This was important as if a fat reading were to emerge as significant in selecting cattle for slaughter, farmers would want an ultrasonic reader that was cost-effective, fast and easy to use, in order to promote uptake of using the measurement on-farm.

4.3.9. External fat readings

The external fat readings consist of both the anal and brisket skin fold thicknesses and in order to obtain these measurements, plastic skin fold calipers were used (plate 4.4 below). The measurements were taken in millimetres and rounded to the nearest millimetre. In order to take the anal skin fold thickness measurement, assistance was needed from a second person. This person pinched the skin fold to the right of the tail head, above the rectum whilst the researcher took the reading from the pinched skin, as seen in Nicholson and Little (1988). The assistant also controlled the tail in order to prevent injury through swishing. The brisket skin fold measurement required only one person to take, providing the animal was restrained with a head collar, which was then tied to the crush in order to prevent injury to the researcher. The measurement was taken as per direction from Lawrence et al., (2012) in which the reading is from the most ventral point of the brisket, directly in front of the forelimbs.

Plate 4.4: Skin Fold Calipers for Measuring Skin Fold Thickness in Cattle

Source: NexGen Ergonomics Inc. (2015).

4.4. DATA COLLECTION

For both of the live-animal studies, data was recorded on paper (Appendices C and D) during the measurement process 24 hours prior to cattle being sent to the abattoir and entered into a Microsoft Excel spreadsheet for analysis. Abattoir feedback was emailed to the researcher approximately one week after the animals had been sent to slaughter. The feedback consisted of the unique identification tag number, sex of the animal, hot carcase weight and EUROP carcase classification achieved according to the standard EUROP grid for carcase classification. In the case of the second study, the carcase classification was based on the 15-point EUROP grid as the cattle were slaughtered at an abattoir owned by ABP Food Group. The classification assigned to the carcase was put into the data spreadsheet alongside the corresponding set of live-animal measurements, determined by matching the unique identification tag numbers.

4.5. DATA MANAGEMENT

Data was originally collected in a paper format (see appendices C and D) and then transferred and stored into separate Excel files for each of the three studies. These files were backed up to an external hard-drive, as well as being stored via email. Original paper copies of all data collected were filed, kept and stored in case of emergency.

CHAPTER 5:

LOGISTIC REGRESSION MODEL LINKING LIVE ANIMAL MEASUREMENTS TO UK PREMIUM CARCASE CLASSIFICATION

5.1. INTRODUCTION

The outcome of this statistical analysis procedure is to see whether a model can be created which helps to determine when cattle are most suitable for slaughter and meet a UK premium carcase classification, based on a selection of live-animal measurements previously described in Chapter Two. The model was constructed through trialling fifteen different live-animal measurements to create a model that is applicable and useful to the real-world setting. The model constructed and measurements selected had to also take into account practical factors, such as ease of taking the measurement from the live cattle on-farm, as the eventual aim was that farmers would be able to replicate these measurements within the working environment.

5.2. AIMS AND OBJECTIVES

The aim of this chapter was to undertake a model-building process necessary to identify the most useful measurements which have a direct relationship with UK premium carcase classifications and to then take these measurements forward as independent variables in binary logistic regression analysis, with UK premium carcase classification as the outcome. The analysis then helps to determine the likelihood of a carcase meeting UK premium carcase classification based on this combination of live-animal measurements taken 24 hours prior to slaughter.

5.3. METHODOLOGY

Binary logistic regression was selected for this stage of the analysis because it is more flexible than ordinary linear regression without assuming linearity, equal variances or normality and it allows for dichotomous (yes/no) outcomes (Statistics Solutions, 2015) based on independent variables that can either be categorical or continuous (Laerd Statistics, 2013). In this analysis, the outcome was whether a carcase attained a UK premium classification or not, firstly based on continuous measurements, which were then categorised into different levels to allow for greater clarity. UK premium carcase classifications are those classifications on the standard EUROP carcase classification grid in which farmers receive the best premiums and returns and the carcases are the subject to greatest UK demand. For the purposes of this study, carcases attaining U-/+3, U-/+4L, R3 and R4L were classified as UK premium, along with any carcases that met the criteria for export (U+2). A 5-step model-building process (University of Sydney, 2017) was used to assess, analyse and determine the most suitable and useful measurements to be used in the final binary logistic regression model.

5.3.1. Assumptions of binary logistic regression analysis

Although binary logistic regression is shown to be more flexible than ordinary linear regression, there are a variety of assumptions that need to be met before running of the model can take place, detailed below (Laerd Statistics, 2013; Statistics Solutions, 2015):

1. The outcome (dependent) variable must be discrete (as in a yes/no answer)
2. There should be no highly correlating independent variables included together in the model

3. There are one or more independent variables which are either continuous or categorical
4. Observations should be independent and mutually exclusive categories

In this study, assumption number 1 is met in that the response variable is coded into the dichotomous 1 and 0 for whether or not the carcase classification of an individual animal met a UK premium category. The number 1 was assigned for yes, the carcase classified in the UK premium category and 0 for failure to meet a UK premium category. Assumption 2 is met in that a correlation matrix was undertaken in the preliminary statistical analysis to ensure that highly correlating variables were not included in the same binary logistic regression model, in order to reduce the risk of multicollinearity occurring. Assumption 3 is met given that all the measurements taken from the cattle were either continuous (in the first instance) and then grouped categorically and the model takes into account combinations of two or three of these measurements in order to see if there is a relationship between them and final carcase classification. All observations were independent as the measurements of cattle took place only once on each individual animal and the dependent variable (whether or not the carcase met a UK premium classification) was mutually exclusive, thus meeting assumption 4.

5.3.2. Variable selection

Doohoo et al. (2003) and McConway et al. (1999) state that when there are a large number of predictor variables proposed for a model (such as in this instance), in order to construct the best and most parsimonious model (i.e. the most simple model with the least variables yet the greatest explanatory power) the variables need to be screened and reviewed so that only the most appropriate ones which have the greatest influence on the response variable are included in the final analysis. It is also said that a large number of predictor variables compared to observations can lead to overfitting of a model (McConway et al., 1999), so again, screening and including only the most appropriate, relevant and practical variables to capture the main features of the model will often lead to improved predictive power of the model. Alongside this, correlations between different measurements also need to be identified to ensure that only one of the correlating variables is included in the model in order to prevent multicollinearity. With the overall aim of this analysis being a tool for farmers to use "out in the field", a large number of measurements (predictor variables) is also simply not practical from a labour and time management perspective, so a combination of two or three non-correlating, practical and significant variables need to be selected for use in the binary logistic regression analysis.

5.3.3. Stage 1 – Descriptive Analysis

The first means of assessing potential variables to be used in the model is to look at the descriptive statistics of each individual variable. It is said that where large sets of data are missing, that variable should be removed from analysis. Doohoo et al. (2003) suggest that at least 10 observations per predictor are needed for inclusion, so with 71 data sets per measurement, there are more than enough observations to meet this suggestion. In table 5.1 below, the relative percentages of cattle falling into each sex are displayed along with the years data was collected. Table 5.2 below then shows the number of carcases falling into each classification level. This allows for a rapid assessment of all the data used in the analysis and to look at what classes most of the cattle in the study culled out at.

Table 5.1: Descriptive Statistics for Sex of Cattle and Year of Data Collection

Variable	**Classes**	**Animals** *n* **(relative % within variable)**
Sex/category	Heifer	17 (23.94)
	Steer	54 (76.06)
Year	2011-2012	17 (23.94)
	2012-2013	17 (23.94)
	2013-2014	17 (23.94)
	2014-2015	20 (28.17)

Table 5.2: Overall Carcase Classification Results

	1	**2**	**3**	**4L**	**4H**	**5L**	**5H**
E	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
U+	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
-U	1 (1.4%)	1 (1.4%)	0 (0%)	1 (1.4%)	0 (0%)	0 (0%)	0 (0%)
R	1 (1.4%)	3 (4.2%)	18 (25.4%)	2 (2.8%)	1 (1.4%)	0 (0%)	0 (0%)
O+	0 (0%)	5 (7%)	14 (19.7%)	10 (14.1%)	0 (0%)	0 (0%)	1 (1.4%)
-O	0 (0%)	2 (2.8%)	1 (1.4%)	6 (8.5%)	0 (0%)	0 (0%)	0 (0%)
P+	0 (0%)	3 (4.2%)	1 (1.4%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
-P	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)

According to the averages taken from combining the results of carcase classifications taken from the EBLEX and AHDB-BL yearbooks between the years of 2012 to 2014, it can be seen that the study sample gives a relatively accurate representation of the current classification situation in that time frame when looking at fat class (Figure 5.2). In contrast, Figure 5.1 below gives a graphical comparison between the national average of conformation between 2012 and 2014 and the study findings, with the study data showing a bias to the right (poorer conformation classes). This indicates that assessing conformation in live animals is more difficult than assessing fat level, as the data for fat class matched much more closely with that of the national average. This can be seen in figure 5.2 which shows a comparison between the percentage of carcases classified at different fat levels and the study sample, with the study sample clearly being fairly representative of the real-world situation.

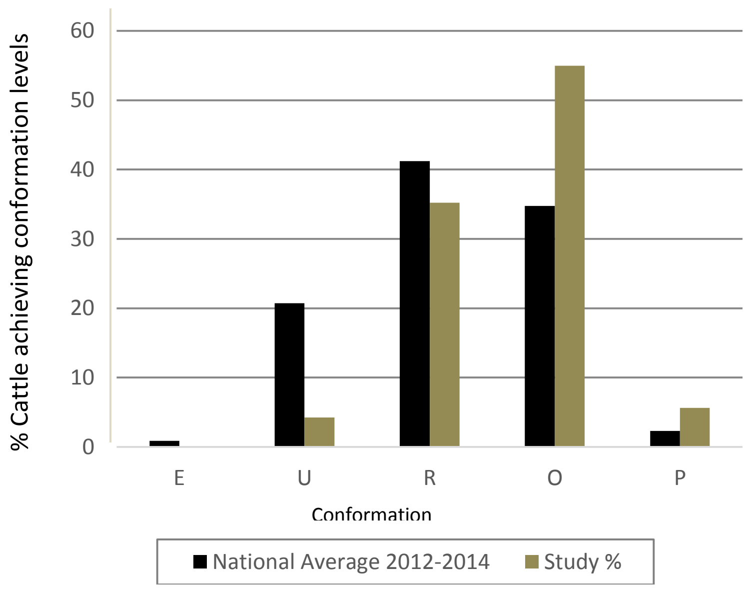


Figure 5.1: Average % of Carcases falling into Conformation Classes between 2012 and 2014 compared with the Study Sample

Source: Adapted from EBLEX (2013a); EBLEX (2014); AHDB (2015)

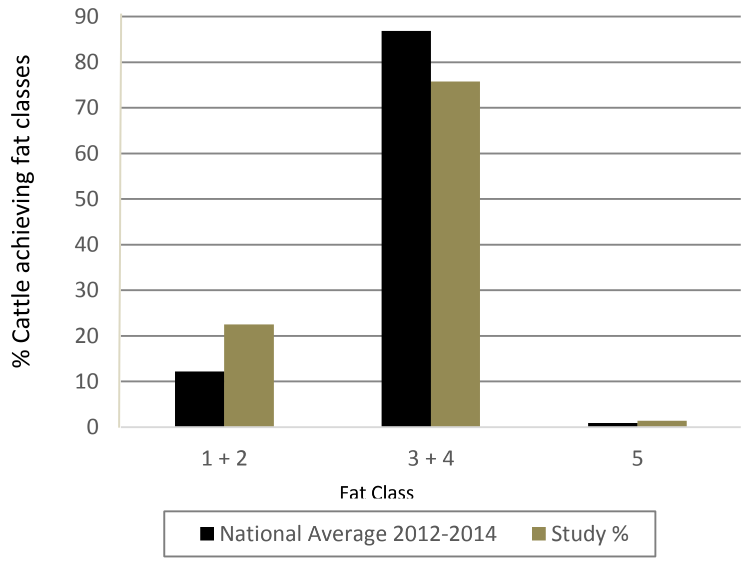


Figure 5.2: Average % of Carcases falling into Fat Classes between 2012 and 2014 compared with the Study Sample

Source: Adapted from EBLEX (2013a); EBLEX (2014); AHDB (2015)

A reason that assessing conformation in live cattle may be more difficult than assessing fat level is that it is much more subjective. When looking at fat levels in live cattle, the EBLEX Better Returns Programme recommends handling cattle at specific regions, with guides to indicate the various fat classes (EBLEX, 2007). However, when assessing conformation, visual appraisal is used to assess the entire animal, which could be affected by the gut fill of the animal making it appear more convex, or the posture in which it is standing. This could mean that although the animal appears to be in suitable slaughter condition, in reality it fails to meet a desired class. Furthermore, one thing that must be taken into account when looking at these graphs is that the study sample originated from a college farm in which for financial and teaching purposes, cattle had to be sent to the abattoir in batches of five or six, which meant that some cattle may have been sent prematurely. This could go some way to explaining why there are some discrepancies in the figures, particularly the lower conformation classes (with a high proportion of the study population attaining an O classification), in which the study percentages were higher than those of the national average.

However, the prime fat classes of 3 and 4, alongside the R conformation were only slightly lower than the national percentages and so therefore are relatively representative of the UK beef cattle industry, and are of most interest and importance to the study.

The next stage of the descriptive analysis is to plot each measurement against the percentage of cattle within each quartile that achieved a UK premium class. This is done to give an idea of distribution and to any patterns which could be displayed between the measurement and UK premium classification. This can then be used to inform further grouping scenarios of measurements in order for further analysis. However, in regards to the numerical values used with the ultrasonic fat depth readings, which cannot be split into decimals and are a whole figure, they are therefore grouped according to a specific measurement value, not quartiles. Table 5.3 below therefore shows the number of cattle which fell into each quartile (or grouping category) according to each different measurement. This was done to see if any quartiles or groups were particularly low or high in numbers (such as the "Very High" quartile for 12th rib fat point reading; n = 6), as this then helped to instruct further grouping scenarios (for example, grouping the "Very High" group for 12th rib along with the "High" group, to create one category for all animals above 7mm of fat, or for splitting down a group with a high number of cattle), in order to get a more balanced spread of data. Table 5.4 then goes on to show basic descriptive statistics (mode, median and mean) associated with each individual measurement.

Table 5.3: Displaying the number of cattle per quartile according to measurement

Measurement	Low/Thin/ Short	Medium	High/Thick/Tall/ Wide	Very High/Thick/Tall/Wide
	Number of cattle in each quartile			
Weight	19	17	21	14
Anal Skin Fold	18	30	8	15
Brisket Fold	24	23	8	16
Wither Height	18	21	15	17
Pelvis Height	16	15	22	18
Wither Width	19	23	15	14
Pelvis Width	18	22	19	12
Rump Width	21	17	21	12
Rump Length	16	18	19	18
Round Profile	20	21	13	17
Back Length	17	24	15	15
Heart Girth	18	20	17	16
10^{th} Rib Fat	12	37	13	9
12^{th} Rib	18	33	14	6
P8 Fat Point	20	28	14	9

The highlighted numbers indicate a particularly low (<10) or high number (>25) of cattle within the quartile. This was taken into account for further grouping scenarios when running the logistic regression analysis, by either joining or breaking down the current groups.

Table 5.4. Descriptive statistics (mode, median and mean) associated with each individual measurement

Measurement	Mode	Median	Mean	Range
10th Rib Fat Point (mm)	6	6	6.3	5 (4-9)
12th Rib Fat Point (mm)	6	6	6.1	8 (4-12)
P8 Fat Point (mm)	6	6	6.3	8 (4-12)
Brisket Skin Fold (cm)	1.4	1.4	1.4	1.7 (0.7-2.4)
Anal Skin Fold (cm)	1.6	1.6	1.6	3.0 (0.7-3.7)
Rump Length (cm)	68	64	63.7	20 (54-74)
Wither Height (cm)	133	136	136	22 (125-147)
Round Profile (cm)	66	70	70	24 (58-82)
Pelvis Height (cm)	140	141	140	28 (127-155)
Back Length (cm)	104	104	105	32 (88-120)
Heart Girth (cm)	202	202	201.8	43 (180-223)
Pelvis Width (cm)	80	74	72.8	44 (44-88)
Rump Width (cm)	80	70	70.1	49 (46-95)
Wither Width (cm)	74	70	66.4	54 (31-85)
Weight (kg)	570	575	577.7	210 (470-680)

It can be seen that from both table 5.3 and 5.4 above that the fat measurements may be more beneficial and useful to the analysis if they were grouped differently, due to the fact there are relatively small numbers of data in the highest grouping category and also that the measurement reading of 6mm appears most frequently, meaning that this particular measurement should remain in a group alone and that the higher valued measurements should be grouped together. This would then result in three grouping categories instead of four. The next stage of the analysis was to look at the percentage of cattle achieving a UK premium class in relation to these quartiles, as this further affirms grouping categories for statistical procedures. A full display of figures from all 15 measurements can be seen in Appendix E.

In regards to weight, heavier cattle (those between 621 and 680kg) do appear marginally less likely to meet a UK Premium class. However, in relation to anal skin fold thickness, there appears to be a trend developing between 0.7-1.9mm, with the cattle with thicker anal skin fold more likely to achieve a UK Premium class, up to a point. The graph for brisket skin fold thickness (see appendix E) indicates that cattle have a greater chance of meeting a UK Premium if they have a 1.5mm (thick) measurement.

With wither height, both “short” and “very tall” cattle appear have a greater likelihood of meeting a UK Premium class at slaughter than the other groups and similarly in regards to pelvis height, both shorter and very tall cattle had a greater chance of achieving a UK Premium class at slaughter. It is seen that cattle with shorter wither width appear to be slightly less likely to achieve a UK Premium class than cattle with a wither width greater than 63cm, though no real relationship between the measurement and success is shown. In regards to pelvis width, there is a far higher percentage of cattle achieving a UK Premium class if their pelvis width is from 75-80cm when compared to the other three categories.

No relationship between rump width and the percentage of cattle within each measurement quartile achieving a UK Premium class is shown, whereas a slight negative relationship with rump length and the percentage of cattle meeting a UK premium class seems to be displayed. Once again, no relationship linking round profile measurements in live cattle with UK premium carcase classifications is displayed.

However, back length portrays a strong positive relationship with the likelihood of cattle achieving a UK Premium class, with 47% of cattle from 109-120cm back length in the study achieving a desired classification. In comparison, only 18% of cattle categorised as “Short” achieved a UK Premium class. Furthermore a positive relationship can be seen in relation to heart girth and the amount of cattle achieving a desired UK Premium class. Larger heart girth in cattle again indicates a greater chance of achieving a UK Premium class, with 41% of cattle within the large quartile achieving a desired class, compared to only 17% in the short category.

In regards to the 10^{th} rib fat point reading, nearly half of all cattle in the "very high" group within this study achieve a desired UK premium class, in comparison to only 17% within the low category, although no further relationship is shown. In contrast, a positive relationship for cattle with a higher 12^{th} rib fat point reading meeting a UK Premium class. Only 21% of all cattle classified as having a medium 12^{th} rib fat depth were shown to meet a desired class, increasing to 43% within the high category. Finally, 50% of cattle with a 7mm P8 fat depth reading within the study did UK premium classification compared to only 33% in the very high category, although no real relationship between the measurement and likelihood of achieving a desired class was shown.

5.3.4. Stage 2 - Univariate Analysis

A univariate analysis tests the unconditional association between one explanatory variable only and the outcome only, without accounting for any other variables or confounders (University of Sydney, 2017). In this instance the explanatory variable is each of the different measurements taken from the live cattle. The P-value given then shows the significance of the association between the measurement and outcome (in this case, UK Premium classification). Odds ratios are then also analysed as these show the type of association (if any) between the variable and outcome. Values greater than 1 indicate a positive association and an increased likelihood of achieving a desired outcome, values less than 1 indicate a negative association and a decreased likelihood of achieving a desired outcome, and values of 1 itself indicate no association. Alongside this, odds ratios can be used to help inform grouping scenarios for each measurement (instead of just using quartiles) as those with similar odds ratios could be grouped together accordingly (University of Sydney, 2017). Due to there only being 6 data sets with both the highest groups of the 10^{th} and 12^{th} ultrasonic fat depth readings, these have been merged with the second-highest to form one category – thus leaving these fat measurements with 3 category groups (Low, Medium, High) instead of four. The higher significance of the P-value, combined with the strength of association between each measurement and UK Premium classification then helps to select which measurements should be carried forward into further analysis and modelling procedures. Table 5.5 below shows the output from the simple logistic regression analysis with each measurement:

Table 5.5. Results from simple logistic regression analysis looking at the association between each measurement and UK Premium classification

Reading	Group	Number *n*	Significance	Odds Ratio	95% CI
W	Light (470-545kg)	19	0.257	0.583	-
	Medium (546-575kg)	17	0.390	0.527	0.123-2.266
	Heavy (576-620kg)	21	0.935	1.055	0.293-3.803
	Very Heavy (621-680kg)	14	0.346	0.468	0.096-2.271
Overall Model Significance: 0.613					
ASF	Thin (0.7-1.2cm)	18	0.027	0.286	-
	Medium (1.21-1.6cm)	30	0.415	1.750	0.456-6.722
	Thick (1.61-1.9cm)	8	0.422	2.100	0.343-12.858
	Very Thick (1.91-3.7cm)	15	0.478	1.750	0.373-8.204
Overall Model Significance: 0.824					
BSF	Thin (0.7-1.1cm)	24	0.020	0.333	-
	Medium (1.11-1.4cm)	23	0.932	1.059	0.285-3.930
	Thick (1.41-1.5cm)	8	0.196	3.000	0.567-15.867
	Very Thick (1.51-2.4cm)	16	0.401	1.800	0.457-7.087
Overall Model Significance: 0.522					
WH	Short (125-132cm)	18	1.000	1.000	-
	Medium (133-136cm)	21	0.047	0.235	0.056-0.982
	Tall (137-139cm)	15	0.083	0.250	0.052-1.198
	Very Tall (140-147cm)	17	0.382	0.545	0.140-2.120
Overall Model Significance: 0.161					

Reading	Group	Number *n*	Significance	Odds Ratio	95% CI
PH	Short (127-136cm)	18	1.000	1.000	-
	Medium (137-141cm)	22	0.018	0.158	0.034-0.728
	Tall (142-144cm)	15	0.083	0.250	0.052-1.198
	Very Tall (145-155cm)	16	0.716	0.778	0.201-3.008
Overall Model Significance: 0.057					
WW	Narrow (31-62cm)	19	0.019	0.267	-
	Medium (63-70cm)	23	0.331	2.000	0.494-8.089
	Wide (71-74cm)	15	0.423	1.875	0.402-8.738
	Very Wide (75-85cm)	14	0.354	2.083	0.441-9.844
Overall Model Significance: 0.755					
PW	Narrow (44-69cm)	18	0.027	0.286	-
	Medium (70-74cm)	22	0.751	0.778	0.165-3.672
	Wide (75-80cm)	19	0.032	4.812	1.114-20.246
	Very Wide (81-88cm)	12	0.860	1.167	0.210-6.484
Overall Model Significance: 0.042					
RW	Narrow (46-62cm)	21	0.009	0.235	-
	Medium (63-70cm)	17	0.142	2.975	0.694-12.756
	Wide (71-80cm)	21	0.707	1.328	0.302-5.843
	Very Wide (81-95cm)	12	0.071	4.250	0.884-20.441
Overall Model Significance: 0.208					

Reading	Group	Number *n*	Significance	Odds Ratio	95% CI
RL	Short (54-61cm)	16	0.323	0.600	-
	Medium (62-63cm)	18	0.800	0.833	0.204-3.409
	Long (64-67cm)	19	0.479	0.595	0.141-2.507
	Very Long (68-74cm)	18	0.546	0.641	0.151-2.719
Overall Model Significance: 0.640					
RP	Short (58-66cm)	20	0.082	0.429	-
	Medium (67-70cm)	21	0.920	0.933	0.243-3.585
	Long (71-73cm)	13	0.963	1.037	0.227-4.728
	Very Long (74-82cm)	17	0.732	1.273	0.320-5.058
Overall Model Significance: 0.975					
BL	Short (88-100cm)	17	0.015	0.214	-
	Medium (101-104cm)	24	0.402	1.922	0.418-8.841
	Long (105-108cm)	15	0.170	3.111	0.616-15.709
	Very Long (109-120cm)	15	0.170	3.111	0.616-15.709
Overall Model Significance: 0.477					
HG	Small (180-197cm)	18	0.011	0.200	-
	Medium (198-202cm)	20	0.340	2.143	0.448-10.255
	Large (203-206cm)	17	0.118	3.500	0.727-16.848
	Very Large (207-223cm)	16	0.178	3.000	0.606-14.864
Overall Model Significance: 0.434					

Reading	Group	Number *n*	Significance	Odds Ratio	95% CI
10th	Low (4-5mm)	12	0.038	0.200	-
	Medium (6mm)	37	0.303	2.400	0.453-12.710
	High (7-9mm)	22	0.415	2.222	0.497-16.427
Overall Model Significance: 0.494					
12th	Low (4-5mm)	18	0.069	0.385	-
	Medium (6mm)	33	0.598	0.700	0.186-2.638
	High (7-12mm)	20	0.376	1.950	0.671-10.065
Overall Model Significance: 0.095					
P8	Low (4-5mm)	20	0.033	0.333	-
	Medium (6mm)	28	1.000	1.000	0.266-3.763
	High (7mm)	14	0.139	3.000	0.699-12.875
	Very High (8-12mm)	9	0.643	1.500	0.270-8.344
Overall Model Significance: 0.383					

Table 5.5 Reading Key: W = Weight; ASF = Anal Skin Fold Thickness; BSF = Brisket Skin Fold Thickness; WH = Wither Height; PH = Pelvis Height; WW = Wither Width; PW = Pelvis Width; RW = Rump Width; RL = Rump Length; RP = Round Profile; BL = Back Length; HG = Heart Girth; 10^{th} = 10^{th} Rib Fat Point Reading; 12^{th} = 12^{th} Rib Fat Point Reading; P8 = P8 Fat Point Reading

It can be seen from Table 5.5 above that the only overall significant model was that of pelvis width (P=0.042), with pelvis height almost showing significance (P=0.057). This indicates that these two variables should be taken forward into the next stage of analysis.

None of the quartile groups for the weight measurement displayed any significance with the outcome and that the odds of cattle achieving desired class were not greatly improved with any of the quartile groups. This indicates that there is not a statistically significant association between weight and whether or not cattle meet a UK premium class at slaughter.

However, a significant association is shown between cattle with a thick anal skin fold (1.61-1.9cm), showing a strong positive relationship, though not significant, with achieving UK premium classification with cattle twice as likely to meet desired class if they fell within this criteria. In regards to brisket skin fold thickness and the relationship between the measurement and UK Premium carcase classification, it can be seen that there is a significant association ($P<0.05$) between thinness of brisket and UK premium classes, with the odds ratio shows that this is a negative relationship (OR = 0.333) so this means that thinner cattle (0.7-1.1cm) are around 66% less likely to achieve a desired carcase classification that suits UK market specification. In contrast to this, thicker cattle (between 1.41 and 1.5cm thickness) display a strong positive relationship, being three times more likely to meet a UK premium class, thus mimicking that of the anal skin fold measurement.

It can be seen when looking at the wither height measurement that no real association is seen between the four quartiles and odds of achieving a UK premium class, with the findings indicating that cattle which are taller at the withers are only very slightly more likely to achieve a UK premium classification than those shorter cattle. This means that this measurement is not likely to be taken into further analysis. Pelvis height follows a relatively similar pattern in regards to association and relationship with UK premium classification as wither height, again indicating that a correlation may be taking place, although the model for pelvis height did prove very near significance.

No real pattern or trend is shown with increasing wither width and likelihood of attaining a desired class when assessing wither width. However, it is seen that the widest cattle are over twice as likely to meet a UK premium standard (OR = 2.083). Similarly, the table shows that cattle with wide pelvises (between 75-80cm) are 4 times more likely and significantly more likely (P = 0.032) to achieve a desirable UK premium carcase classification, with the overall model for pelvis width proving significant (P = 0.042) This indicates that the wider the cattle are at the pelvis, the greater the likelihood of meeting a desirable UK premium classification, but only up to a point. This can be seen in that cattle with a pelvis of over 81cm in width are only 16% more likely (OR = 1.167) of achieving a desired class.

In regards to rump width, it can be noted from table 5.5 that narrow cattle are significantly less likely ($P < 0.05$) to achieve a UK premium class. In contrast however, those cattle with a very wide rump (greater than 81cm) are almost four times as likely to achieve a desired class. However, a strong positive relationship between increasing rump width and likelihood of achieving a UK premium class is not clearly demonstrated. No relationship or significance between UK premium classification and rump length measurement is shown. In contrast, length of the round profile in cattle is shown to have a slight positive relationship with the likelihood of cattle meeting UK premium classes, in that the longer the round profile, the more likely they are to meet a desired class. Cattle with the largest round profile (between 74 and 82cm) are 27% more likely to actually meet desired class (OR = 1.273).

It can be seen from Table 5.5 above that cattle with back lengths of over 105cm were almost three times as likely to meet a desired UK premium class and that an increasing likelihood of meeting a UK premium class is shown with increasing back length. These results indicate that a strong positive relationship is shown between increasing back length and meeting market specification at slaughter. Interestingly, it can be seen relationship between heart girth and UK premium classification follows a similar pattern to that of back length, with a greater chance of cattle with larger heart girths (over 203cm) reaching a desired classification (three times as likely). Similarities are also displayed in cattle with shorter heart girths (180-197cm) being significantly ($P<0.05$) less likely to achieve desirable classifications.

A slight positive relationship can be also seen between 10th rib fat point reading and UK premium carcase classification in that cattle with the highest fat readings between 8 and 9mm were 3 times more likely to achieve a UK premium classification. In contrast to this, thinner cattle with a 10th rib reading between 4 and 5mm were significantly less likely to do so ($P = 0.038$). Furthermore very strong positive relationship is seen between 12th rib fat point reading and likelihood of meeting a UK premium class. Cattle with a high fat depth reading of 7mm were 95% more likely to meet desired class and this was further raised to cattle with the highest fat depth reading being over 4 times as likely to attain a premium specification (OR = 5.2). In relation to the P8 fat point reading, cattle falling in the high category (7mm) were three times as likely to meet a UK premium class, but this decreased once cattle exceeded 7mm, to only a 50% increased chance of achieving specification if cattle measured between 8 and 12mm (OR = 1.5). This therefore shows that in this instance, the ideal optimum measurement for a P8 fat reading is 7mm, which cattle having a much greater chance of meeting a UK premium classification.

5.3.5. Stage 3 - Correlation Analysis

Undertaking a correlation analysis of all potential predictor variables would enable any variables which communicate the same information (correlate) to be eliminated. Elimination of correlating variables is highly important as otherwise the model will be subject to collinearity which produces unstable estimates of coefficients as well as problematic standard errors as it is just like including repeats of information already given by one variable

(McConway et al., 1999; Doohoo et al., 2003). The selection of which correlating variable to use in the final model in this study was therefore based on the ease and practicability of taking the measurement in a farm environment as well as the relationship seen between the measurement and UK Premium classification assessed in the previous two stages. The output from performing the correlation analysis is shown below in Table 5.6 with all of the correlating variables highlighted and the highly correlating variables (>0.7) marked with two asterisks (Calkins, 2005). Doohoo et al. (2003) state that collinearity is a problem with correlation coefficients greater than 0.9 but that it can be a problem at lower levels (such as >0.5) (Calkins, 2005).

Table 5.6: Correlation Analysis demonstrating the correlations between 15 live-animal measurements

							Measurement							
	W	**ASF**	**BSF**	**P8**	**10**	**12**	**WH**	**PH**	**WW**	**PW**	**RW**	**RL**	**BL**	**HG**
ASF	0.06													
BSF	0.36	0.08												
P8	0.02	0.04	0.02											
10	0.07	0.22	0.02	0.23										
12	0.01	0.23	0.10	0.30	0.28									
WH	0.52	0.18	0.01	0.24	0.23	0.20								
PH	0.41	0.34	0.04	0.13	0.20	0.29	0.79**							
WW	0.09	0.49	0.29	0.04	0.04	0.26	0.17	0.21						
PW	0.00	0.25	0.14	0.07	0.16	0.10	0.26	0.12	0.57					
RW	0.07	0.22	0.06	0.36	0.12	0.27	0.08	0.22	0.26	0.54				
RL	0.45	0.03	0.02	0.04	0.08	0.17	0.40	0.32	0.04	0.04	0.23			
BL	0.45	0.16	0.28	0.16	0.04	0.18	0.60	0.62	0.12	0.06	0.07	0.45		
HG	0.65	0.02	0.31	0.14	0.13	0.02	0.46	0.39	0.04	0.01	0.02	0.47	0.60	
RP	0.34	0.22	0.03	0.04	0.10	0.22	0.29	0.10	0.24	0.14	0.20	0.38	0.05	0.20

Key: W (Weight); ASF (Anal Skin Fold); BSF (Brisket Skin Fold Thickness); P8 (P8 Fat Point Reading); 10 (10^{th} Rib Fat Point Reading); 12 (12^{th} Rib Fat Point Reading); WH (Wither Height); PH (Pelvis Height); WW (Wither Width); PW (Pelvis Width); RW (Rump Width); RL (Rump Length); BL (Back Length); HG (Heart Girth); RP (Round Profile).

It can be seen from the correlation matrix displayed it table 5.6 above that there are eight correlations greater than 0.5 displayed between the measurements. It is therefore necessary to eliminate one variable from each of these pairs in order to prevent multicollinearity within the final model. The measurement combinations displaying a correlation are shown below:

1. Weight + Wither Height

2. Weight + Heart Girth

3. Wither Height + Pelvis Height

4. Wither Height + Back Length

5. Pelvis Height + Back Length

6. Wither Width + Pelvis Width

7. Pelvis Width + Rump Width

8. Heart Girth + Back Length

When looking at the correlation combination number 1 (weight and wither height), the obvious choice is to keep weight in the analysis and drop wither height. Not only is weight far more objective than wither height to take in live cattle, but it is also more practical and something farmers do on a regular basis anyway. Keeping weight as a measurement also therefore eliminates heart girth from the next stage in the analysis; again weight is far easier and more practical than heart girth to take on-farm, thus dealing with correlation seen in combination number 2. The correlation combinations seen in 3, 4 and 5 mean that only one of either wither height, pelvis height or back length can be taken forward. Pelvis height provides the most repeatable measurements using "bony landmarks" and is again more practical to take on-farm. For these reasons, pelvis height is to be kept while back length and wither height were excluded from further analysis. With combinations 6 and 7, pelvis width provides the most accessible and repeatable measurements than either of the other two "width" measurements. Rump and wither width were therefore eliminated in further analysis. With heart girth and back length decided to be removed from analysis due to correlations seen with other measurements, correlation combination 8 is now redundant.

5.4 PRELIMINARY ANALYSIS DISCUSSION

5.4.1. Live weight and external fat readings

It can be noted that in regards to the live weight measurement taken from cattle, that the pattern of success in the percentage of cattle achieving a UK premium class across these measurement groups (with heavier cattle slightly less likely to meet a UK premium class) is reflective of other research. For example, EBLEX (2007) state that the ideal carcase weight for supermarkets is approximately 260-370kg. This means that with carcase weight for beef cattle falling between 58-62% of total live-weight (Rentfow, 2010), the ideal range for weight in live animals in order to meet supermarket specification (and subsequently UK Premium classes) should be between 433 and 616kg; which in turn covers the first three quartiles and could then go on to explain why the heaviest cattle were slightly less likely to meet a UK Premium classification. However no real relationship was demonstrated between the increasing or decreasing of weight and the attaining of a UK premium class. It was also found through the correlation matrix (table 5.6) that weight correlates with both wither height and heart girth within this study (0.52 and 0.65, respectively). However, due to weight being the most practical, reliable and objective measure to obtain from live cattle on-farm out of these three measurements, and with the data collected reflective of that of other studies, it was concluded that live weight would be taken forward into the next stage of the modelling procedure.

In regards to anal skin fold thickness, table 5.5 shows that there is a slight positive relationship is shown between increasing anal skin fold thickness in live cattle and the odds of achieving a UK premium classification, up until a point (1.9cm). This concurs with the idea that cattle need to be of a certain fat level in order to fall into the UK premium specification area of the EUROP carcase classification grid, and that animals over this are less desirable for the UK beef market. Anal skin fold thickness is also shown to have no correlations with any other measurements, however when assessing practicality for on-farm application and looking at past research which often states the requiring of two people to record this fat reading accurately (Nicholson and Little, 1988), the anal skin fold thickness measurement is therefore deemed inappropriate for everyday use due to it being labour-intensive and difficult to replicate (Somervaille et al., 1986), and was subsequently dropped from further analysis. With brisket skin fold thickness, table 5.5 again shows this slight increase in odds of cattle achieving a UK premium class as brisket skin fold increases, up until a point, with cattle in the “thick” quartile three times more likely to meet UK premium. Like anal skin fold thickness, the brisket skin fold thickness measurement showed no correlation with any other measurement taken from live cattle, meaning it could be used in any future model combination as there is no risk of multicollinearity. Furthermore, it is slightly easier to administer on-farm and is less labour-intensive as it does not necessarily require two people to take the reading. It is for these reasons that brisket skin fold thickness was taken forward into the next modelling stage.

5.4.2. Morphometric Measurements

In regards to wither height, the descriptive analysis displays that cattle which fell into both the short and very tall quartiles have a much higher percentage of cattle achieving a UK premium class in this study, and there is research to support both of these findings (Black et al., 1938; Coopman et al., 2013). Shorter cattle may indicate a stockier, blockish form which has previously been desired within the beef industry (Black et al., 1938) whereas taller cattle could indicate more muscular shoulders to support the height, again pointing towards a better classification at slaughter. However, when looking at the odds ratios in table 5.5, a very slight increase is seen in the chances of cattle achieving a desired classification as they get taller, again concurring with past research by Coopman et al. (2013). Rather obviously, wither height and pelvis height are shown to display a very strong correlation (0.79) and more interestingly, a correlating relationship is also displayed between wither height and back length measurement (0.60) and also with weight (0.52).

Pelvis height offers easier points of reference (hook bones) when measuring height, thus making it easier to apply on-farm. Furthermore, the lack of real trend of increased chances of cattle meeting UK premium as they get taller at the withers, and with weight (of which wither height also correlates with) already being selected for further analysis it is for these reasons that wither height was eliminated from further modelling procedures. The spread of odds ratios for this pelvis height are far greater for the quartile groups than that of wither height, therefore indicating that is more of a distinct chance of cattle either meeting or not meeting a premium grade depending on which measurement quartile they fall into. Pelvis height shall subsequently be taken into further modelling procedures.

No real relationship or pattern is shown at all in regards to increasing wither width and the percentage of cattle meeting desired class. This lack of trend or relationship between the measurement and outcome is further emphasised when looking at the odds ratios for each quartile in table 5.5. This indicates that increasing wither width does not necessarily mean that the chances of meeting a desired UK premium classification are increased. Furthermore, wither width has been shown in table 5.6 to correlate with pelvis width (0.57). The pelvis width measurement offers a more reliable and accurate measurement reading due to the use of bony land marks (hook bones) rather than relying on muscle convexity and is therefore easier to apply on-farm. Due to this combination of factors, it is therefore decided that wither width was dropped from further analysis.

According to the descriptive statistics, it can be noted that those cattle with pelvises between the measurements of 75-80cm appear to have a greater chance of meeting a desired class. This is further backed up when looking at the odds ratios in table 5.5, as cattle in the "wide" pelvis width category are four times as likely to meet a UK premium classification. A wider pelvis could be indicative of a broader, stockier animal, which is considered desirable within the UK beef industry. Correlating relationships are seen between pelvis width and rump width (0.54) as well as pelvis width and wither width (0.57). From a practicality and accuracy aspect, the measuring across the pelvis using the hook bones as "bony landmarks" is far easier and reliable to perform on-farm than either rump or wither width. Pelvis width has also been used to assess dystocia rates in beef cattle (Murray et al., 2002) and is also a good indicator of body weight (Alderson, 1999), thus promoting its inclusion in the study. It is for these reasons that pelvis width be carried forward into the next stage of analysis and both rump and wither width eliminated.

A slight negative trend is being displayed in regards to rump length and the percentage of cattle meeting UK premium, indicating that the percentage of cattle within the rump length measurement quartile in the study which meet UK premium actually decrease as the length of rump increases, which is contrary to other studies, such as Coopman et al. (2004). Reasons for this could be that cattle with a longer rump length are taller overall, and taller cattle are more likely to be of a dairy-build type (Black et al., 1938), and are therefore leaner with less fat coverage and with less desirable conformation. Furthermore, in table 5.5 when observing odds ratio, medium cattle (62-63cm) are slightly more likely to achieve desired classes. These findings from the preliminary analysis do make rump length an interesting measurement to pursue further and with it not being shown to correlate with any other measurement, it is potentially a suitable candidate to take into further exploratory statistical modelling.

A very slight positive relationship is displayed in the descriptive statistics graph in relation to the round profile measurement, indicating that the more convex the animal, the more likely it is to meet a desired class. This concurs with research and manuals by EBLEX which suggest that when assessing live cattle, to look for those more round in shape, as convexity is indicative of better conformation and subsequently better classification at slaughter. This positive trend is further emphasised when looking at the odds ratio in table 5.5, although none of the quartiles for round profile proved significant. Alongside this trend, there are no correlations displayed between round profile and any of the other fourteen measurements taken from live cattle. This slight trend with increasing likelihood in UK premium classification alongside increasing round profile length and lack of correlation with other measurements means that round profile is suitable for use in the final modelling procedure.

As seen in Appendix E a strong positive trend is shown with increasing back length and the percentage of cattle attaining a UK premium classification. This concurs with research from Aass (1996) who found that cattle with longer carcases had a better growth rate and lower intramuscular fat. A better growth rate indicates that there is better muscle development in the animal, subsequently leading it to a better classification at slaughter. This positive trend is further shown when assessing odds ratios in table 5.5, in which cattle with back lengths over 105cm are three times as likely to successfully meet desired classification. However, it is seen that back length correlates with heart girth (0.60). As back length is shown to correlate with wither and pelvis height as well, and with the practicality and ease of taking this measurement more difficult in an on farm setting more difficult than taking that of the pelvis height measurement (and potentially requiring the use of two people in particularly long animals), it is decided that for this correlation and practicality issue, back length should also be eliminated from the analysis.

Heart girth shows a similar trend in regards to the percentage of cattle in each measurement quartile achieving a UK premium classification to back length within this study, understandably explaining the correlation also seen with back length (0.60) Furthermore, when looking at the odds ratios in table 5.5, the larger animals are again three times as likely to attain these desired classes. However, with heart girth (in large cattle especially) notoriously difficult to measure and having a direct relationship with weight, correlating within this study (0.65), as well as being shown in studies by Alderson, (1999); Goe et al., (2001); Heinrichs et al., (2007) and Swali et al. (2008) to be linked to the weight measurement and with weight a far easier and more objective measurement to take from live cattle, it is therefore decided that heart girth be removed from further analysis.

5.4.3. Ultrasonic Fat Depth Readings

10th rib fat point reading shows no correlation with any other measurement and has been shown to be useful in predicting the fat level in beef cattle, and it is fat level which plays an important role (in conjunction with conformation) in post-slaughter carcase classification according to EU standards. Alongside this, this fat reading shows a positive relationship with the likelihood of achieving a desired carcase classification, demonstrating an increased chance of UK premium success with a greater fat depth reading. Furthermore, with the objectivity involved in taking this measurement and relative practical ease of acquiring the reading, the 10th rib fat point reading is therefore ideal to be taken forward into further statistical analysis. A positive relationship is shown when looking at the odds ratios in table 5.5, with those cattle in the highest measurement group twice as likely to meet a premium class. This makes the 10th rib fat point reading suitable to take forward to the next stage of analysis.

Like the 10th rib fat point before it, the 12th rib fat point reading shows no correlation with any other measurements. The 12th rib fat point reading is also used commercially in Australia as a reliable method of determining suitability for slaughter (McKiernan and Sundstrom, 2006), and so it was interesting to see if this translates across borders and can be applied to European cattle and desirable carcase classifications. All of these factors mean that this live animal measurement would be suitable to be used in further modelling analysis.

P8 fat point, like the 12th rib fat point reading has also been used commercially, with success, in Australia (McKiernan and Sundstrom, 2006) to assess suitability in cattle for slaughter, so again it was of interest to see whether this can be applied to commercial cattle within the UK beef industry. Further to this, in looking at the odds ratio, it is noted that cattle in the high group (7mm fat depth reading) were three times as likely to meet a UK premium classification, which interestingly enough, is around the ideal fat depth reading according to the study by Knee (2006). Like the other two ultrasonic fat depth readings, P8 fat point also shows no correlation with any other independent variable. It is also an objective and easily accessible measurement to take from live cattle, with proof of validity and usefulness to the industry. For these reasons, P8 fat point reading was analysed in further binary logistic regression analysis modelling.

5.5. STAGE 4 – MULTIVARIABLE ANALYSIS

The next stage of the model-building process is to take forward these nine selected measurements in order to create a model which helps to predict the likelihood of cattle meeting a UK premium classification. The way this is done is to perform a binary logistic regression with each individual measurement against the outcome (UK premium or not) first, finding the measurement which has the greatest predictive power in achieving a UK premium class compared to the null model. The following stage is to then add in the next best measurement in regards to improving the predictive power of the model and then the next and so forth, until the model can be improved no further. The outcomes from this first stage of the forward stepwise binary logistic regression analysis are shown in table 5.7 below, with pelvis width proving to have the greatest predictive power out of all nine measurements, followed by pelvis height and then the three ultrasonic fat readings.

Table 5.7. Forward stepwise binary logistic regression model building using live animal measurements to predict likelihood of achieving a UK Premium carcase classification

Step	Measurement	Significance	Model Predict
NULL	NULL	NULL	69%
1	Pelvis Width	0.035	73.2%
2	Pelvis Width + Pelvis Height	0.009	78.9%
3	Pelvis Width + Pelvis Height + 12^{th} Rib	0.011	81.7%
4	Pelvis Width + Pelvis Height + 12^{th} Rib + P8 Fat Point	0.009	84.5%
5	Pelvis Width + Pelvis Height + 12^{th} Rib + P8 Fat Point + 10^{th} Rib	0.006	85.9%

It can be seen from the table above that the predictive power of the model has gone from 69% (the null model) up to 85.9% with a significance of P=0.006 when pelvis width, pelvis height and the three ultrasonic fat readings are included. The model building process was terminated after the addition of the fifth measurement as not only did the model no longer improve any further, but for labour and practicality purposes, any more than five measurements per animal would be too laborious and time-consuming to apply on-farm.

After the model was created and could be improved no further, each measurement was then split into different grouping categories (as directed by the previous preliminary analysis). These categories are based on specific measurements whilst ensuring that each category had a sufficient amount of data to validate the model. The model was then re-run using categorical, rather than continuous, independent variables in order to allow for more precision and accuracy when selecting and measuring cattle for slaughter. This allows for farmers to measure their own cattle and identify which category their animal falls into, thus allowing them to predict how likely their animals are to meet a UK premium class. The results from the next stage in the analysis are shown in table 5.8 below:

Table 5.8. Final binary logistic regression model for the likelihood of achieving a UK premium carcase classification according to different live-animal measurements

Measurement	Level	Number *n*	Significance	Odds Ratio	95% CI
Overall Model Significance: 0.010					
Constant	-	-	0.301	0.301	-
Pelvis Height (Short) Reference	127-136cm	18	-	-	-
Pelvis Height (Medium)	137-141cm	22	0.053	0.173	0.029 – 1.023
Pelvis Height (Tall)	142-155cm	31	0.502	0.590	0.126 – 2.759
Pelvis Width (Narrow) Reference	44-69cm	18	-	-	-
Pelvis Width (Medium)	70-74cm	22	0.914	0.909	0.163 – 5.061
Pelvis Width (Wide)	75-80cm	19	0.013	8.716	1.584 – 47.955
Pelvis Width (Very Wide)	81-88cm	12	0.980	1.026	0.139 – 7.595
12^{th} Rib (Low) Reference	4-5mm	18	-	-	-
12^{th} Rib (Medium)	6mm	33	0.384	0.469	0.085 – 2.580
12^{th} Rib (High)	7-9mm	20	0.538	1.715	0.308 – 9.560
P8 Fat Point (Low) Reference	4-5mm	20	-	-	-
P8 Fat Point (Medium)	6mm	28	0.946	1.060	0.196 – 5.747
P8 Fat Point (High)	7-12mm	23	0.143	3.902	0.631 – 24.109
10^{th} Rib (Low) Reference	4-6mm	49	-	-	-
10^{th} Rib (High)	7-9mm	22	0.594	1.467	0.359 – 5.999

5.5.1. Multivariable analysis results

According to the table above, it can be seen that medium cattle (from 137 to 141cm) were more likely to meet a UK premium class, although this was not quite significant (P = 0.053). Increasing the sample size in the next stage of the research may help to see whether cattle within this height category are more likely to achieve a UK premium classification. However, the fact that these relatively tall cattle were more likely to meet a desired carcase class does concur with McKiernan et al (1998), who found that taller cattle grew more quickly and laid down less fat than shorter cattle. This would work with today's EUROP carcase classification grid as it is the slightly leaner cattle which are more desirable for the modern-day supermarket and therefore would subsequently cull out with a UK premium carcase classification, thus accounting for the taller cattle being more likely to meet one of these classes.

It can be seen that in regards to pelvis width, cattle with a pelvis width of 75-80cm were significantly more likely to meet a UK premium class (P = 0.013), with the odds of them reaching this category increased up to eight times (OR = 8.716). This again concurs with past research directly relating to the carcase classification grid, in particular relation to carcase conformation, with those achieving the greatest conformation (such as the E and U categories) being described as "wide and thick" along the back and rump regions (Lazzaroni et al. 2007).

In terms of the fat readings, cattle with 10th and 12th rib fat point readings of 7-9mm were more likely to achieve a UK premium classification than cattle with a less dense fat layer across the ribs, although this was not significant (P = 0.594 and P = 0.538, respectively). The same is also true of the higher P8 fat point reading, with those of a reading of 7-12mm almost four times more likely to meet desired class (OR = 3.902), although again this was not significant. This means that it can be concluded from this model created using five fat and morphometric measurements that cattle with a pelvis height of 137-141cm; pelvis width of between 75-80cm and P8 and rib fat readings of over 7mm are more likely to meet a UK premium carcase classification than those shorter, narrower and thinner cattle.

5.6. Stage 5 – Model Diagnostics

The strength of this model created was then tested by removing five random sets of cattle measurements from the main data set. A significant decrease in the percentage of cattle accurately predicted by the model as achieving a UK premium classification would mean that the model is weak. The results from re-running the model twice after removing two lots of 5 random data sets are shown in the table below, compared to the predictive power of the original model.

Table 5.9. Testing the strength of the model

Step	Measurements	Original Model % predicted correctly	Re-run 1 (eliminating sets 5, 15, 25, 35 and 45)	Re-run 2 (eliminating sets 20, 30, 40, 50 and 60)
Null	-	69%	69.7%	69.7%
1	PW	70.2%	71.2%	71.7%
2	PW + PH	72.9%	74.3%	72.1%
3	PW + PH + 12	76.7%	78.3%	75.3%
4	PW + PH + 12 + P8	80.5%	79.4%	78.5%
5	PW + PH + 12 + P8 + 10	79.9%	82.8%	81.4%

It can clearly be seen from table 5.9 above that there was only approximately a +/- 1% change in the percentage of cattle accurately predicted as meeting a UK premium carcase classification when a random 5 data sets were removed from the original model. This indicates that the model is therefore relatively strong and would be possible to use with a significantly larger data set. The next stage was to test the sensitivity and specificity of the model created, as well as to look at the positive and negative predictive values. Table 5.10 below shows the true and false positive and negative results produced from the model.

Table 5.10. True and false positive and negative results produced from the binary logistic regression analysis linking live-animal measurements to UK premium carcase classification

	Predicted: Didn't Meet UK Premium	Predicted: Met UK Premium
Observed Didn't Meet UK Premium	46 (TN)	3 (FP)
Observed Met UK Premium	10 (FN)	12 (TP)
Accuracy (Overall % correctly predicted by the model	81.7%	

Key: TN = True Negative; FP = False Positive; FN = False Negative; TP = True Positive

The following equations were then used to work out sensitivity, specificity and both positive and negative predictive values of the model:

Sensitivity = TP / (TP + FN) = 54.6%

Specificity = TN / (FP + TN) = 93.8%

Positive Predictive Value = TP / (TP + FP) = 80.0%

Negative Predictive Value = TN / (TN + FN) = 82.1%

It can be seen from table 5.10 that the percentage of results correctly predicted by the model (accuracy) was 81.7%. This was a relatively high increase from the null model, which only accurately predicted 69%. It can also be seen from the percentages above that the ability of the model to correctly identify cattle which have met a UK premium classification (sensitivity) was relatively low at 54.6% when compared to the model's ability to identify those which don't (specificity) at 93.8%. This means that the model was far better at identifying true negatives rather than true positives. However, if the model predicted that cattle would achieve a UK premium classification, they were 80% likely to actually meet a desired UK premium class, according to the positive predictive value. In contrast, if the model then predicted cattle would NOT achieve a desired class according to the negative predictive value, there was an 82.1% chance that they will not do so. This means that the although the model had a relatively low sensitivity for identifying cattle which have met UK premium classification (at 54.6%), the cattle which it did identify as meeting the desired class had an 80% chance of actually doing so.

5.7. DISCUSSION

The aim of this study was to see whether a combination of morphometric and fat measurements taken 24 hours prior to being sent to the abattoir could be used to predict the likelihood of cattle meeting a UK premium carcase classification. A selection of 15 live-animal measurements was initially analysed (see Chapter 4), with these being narrowed down through statistical analysis procedures to 5 measurements (pelvis height and width and 10th rib, 12th rib and P8 fat point readings) which, when put into a binary logistic regression model, could help predict the likelihood of cattle achieving a UK premium class. The model created using these measurements improved the predictive power of the null model from 69% up to 81.1% when all five measurements were entered into the model. It was discovered from this model that cattle 137-141 cm high at the pelvis, with a pelvis width of 75-80cm and fat readings of over 7mm were more likely to achieve a UK premium carcase classification. The model was good at identifying cattle which had not met a UK premium class, furthermore almost 80% of cattle which were predicted to meet a UK premium class actually did so although the model was less accurate at identifying those which did actually meet the grade. With only half of all cattle (50.6%) meeting a UK premium carcase classification in 2016 (AHDB, 2017), if the model predicted an animal would meet UK premium, then it was 80% likely to do so. This means that farmers can reliably trust sending that animal to slaughter and achieving optimum pay if it falls within the set of measurements required by the model. The model was also good at identifying those cattle which would not meet UK premium, with a specificity of 93.8%. This means that after measuring, the farmer could either hold those cattle back for longer, until they fit required measurements, or it could indicate that they have held the cattle back for too long and therefore need to reassess their management practices for future sending in order to meet optimum carcase classifications.

In terms of the time taken to physically measure and assess each animal, it takes approximately two minutes for an experienced assessor to take the measurements, with this time being decreased in the animal is used to the handling facility and if there is assistance in the measuring process. This means that it should not be too labour-intensive or time-consuming once the farmer has become accustomed to the measuring process. This is important if uptake of these measurements by farmers is to be a success as they are more likely to adopt these methods if they are shown to be fast and easy to take from live cattle.

Pelvis height and width and the 10^{th} rib, 12^{th} rib and P8 fat point readings were identified as having a relationship with the UK premium carcase classification. Interestingly in this study, no correlation was shown between the P8 fat point and the 12^{th} rib fat point, which is in contrast to the New South Wales “Rump to Rib” ratio in which this combination of fat readings are used to assess fat level and determine suitability for slaughter through the use of a fat score based on these two measurements in Australian beef cattle (McKiernan and Sundstrom, 2006). A reason for this firstly could be that the categories for both the 12th rib and P8 fat point readings in the New South Wales ratio are different to the ones used in this study. For example, for a fat level score of 3 in the NSW ratio, the P8 reading is between 7 and 12 and the 12th rib fat point reading is between 4 and 7 (McKiernan and Sundstrom, 2006). In contrast, the "high" categories for this study were 7-12 for the P8 reading and 7-9 for both the 12th rib and 10th rib readings. Furthermore, breed differences between the cattle in this study and those out in Australia could go some way to explaining why a relationship between the measurements is shown in the NSW ratio yet not in the live cattle used in this study. The finding that the 10th rib fat point reading plays are role in determining whether or not cattle achieve a UK premium carcase classification does concur with other studies however. It is well known that the 10th rib reading is a good predictor of carcase composition and fat level (Olivan et al., 2010; Font-i-Furnols et al., 2014) and so if this measurement directly relates to carcase composition and fat level, then it is of no real surprise that increasing fat level (up to a point) read on the 10th rib has a relationship with likelihood of achieving the desired carcase outcome.

This finding that medium cattle, wider in the pelvic/loin region, more likely to meet UK premium classification concurs with the current EUROP carcase classification system in that the more convex, larger animals achieve the better conformation classes (Lazzaroni et al. 2007). However, cattle with the higher fat readings being more likely to achieve a desired UK premium class seems to go against the current carcase classification system, in that fatter carcases (those grading at 4H/5L/5H) are penalised and are seen as less desirable to the UK market specification than those slightly leaner carcases (EBLEX, 2011). An explanation for this finding could be that even the cattle in this study with the highest fat readings may not necessarily be deemed excessively fat and thus their carcases fail to fall into the higher fat bands, meaning that they meet the more valuable 3 and 4L fat classes, thus explaining why the cattle in the "high" ultrasonic fat reading categories were more likely to meet UK premium classification.

The fact that the predictive power of the model barely changed when 5 random subjects were removed from the analysis shows that the model was valid and reliable. Furthermore, the chance of cattle meeting a UK premium class is 80% if the model correctly identifies them as likely to meet this specification. Therefore this means that these 5 live-animal measurements could be taken forward and trialled on a larger sample of beef cattle, to see if breed had an impact on the likelihood of meeting a UK premium class as well as to see if the model could be applied to a more commercial beef finishing unit within the UK.

5.7.1. Data limitations and improvements

One of the limitations of the study was the relatively small sample size. The sample consisted of 71 cattle which could explain why so few groups proved to be significant in Table 6.4, due to a thin spread of data across each category. For a more detailed analysis, the sample size would have to be increased in order to be more representative of the UK beef industry. It would also be of interest to group cattle into different categories according to breed, to see whether this impacts of the likelihood of them achieving UK premium carcase classification. Another limitation of the study was that cattle had to be sent in batches of between 4 and 6 animals in order to be cost-effective for the college farm. This meant that some cattle were sent too early before they were fully finished, which could account for why the data set was slightly biased towards cattle meeting poorer conformation classes when compared with the national average. In an ideal world, there would be a much larger data set and cattle would be grouped specifically to try and meet different classes on the EUROP grid post-slaughter; for example, some would be deliberately over-finished or under-finished, in order to try and get a full range of carcase classifications to be used in the model. This would mean that, with a much larger data set, comparisons between measurements of cattle meeting UK premium and not meeting UK premium would be far easier to determine, thus making the study far more applicable and useable to the UK beef industry.

5.8. CONCLUSION

This study narrowed down fifteen live-animal measurements to produce a model using only five specific morphometric and fat measurements which shows that taller, wider and slightly fatter cattle have a greater chance of meeting a UK Premium carcase classification. However, this study only looks at a relatively small sample of commercial cross-bred beef cattle finished on a university farm, without considering the role that breed has to play on morphometrics, fat level and likelihood of meeting a UK premium carcase classification. With farmers looking more and more into specialising in specific breeds or crossbreeds in the future, it will therefore be beneficial to the industry to understand which breeds are most suited to the UK market specification and carcase classification scheme. Furthermore, a larger sample size of true commercial, finishing beef cattle will test and improve the model's validity and reliability, whilst allowing for comparisons between different breeds to be made.

CHAPTER 6:

BREED INFLUENCE, MORPHOMETRIC AND ULTRASONIC FAT MEASUREMENTS IN LIVE CATTLE AND THE LIKELIHOOD OF ACHIEVING A UK PREMIUM CARCASE CLASSIFICATION

6.1 INTRODUCTION

Following on from the model created in chapter 7 using the five morphometric and fat measurements discovered to have a relationship with UK premium carcase classification (these being pelvis height and width, 10^{th} rib, 12^{th} rib and P8 fat point readings), the aim of this final study was to test the model created on a larger scale in order to test the validity of the model in a real-life commercial setting. With past research also indicating towards differences in ultrasound and morphometric measurements, as well as growth rates, between different cattle breeds, such as Peña et al. (2014), who found that growth rates in charolais bulls was higher than that of limousin and retinta breeds and that the retinta breed had a less desirable carcase conformation than both French breeds at slaughter, scoring R to R- rather than U to U- measurement comparisons between different breeds of cattle used within this study were also made. These comparisons were done in order to determine whether specific breed influences the likelihood of meeting a UK premium class, and which breeds performed best in terms of meeting UK premium carcase classifications. This study made use of the more specific 15-point EUROP grid of carcase classification.

6.2 MATERIALS AND METHODS

Over a two-month period (June-July 2017), 120 commercial beef cattle were measured by the researcher 48 hours prior to slaughter at a large beef farm in North Yorkshire. The measurements taken are described in detail in chapter 4 and involved the pelvis height and pelvis width as well as the 10^{th}, 12^{th} and the P8 ultrasonic fat point readings using the RENCO Lean-Meater. Cattle were reared in intensive, American-style feedlot systems and fed a cereal-based concentrate with ad-lib silage. However, Aberdeen Angus cattle were kept separately from the other cattle and finished intensively on a cereal-based diet only. When measurements were being taken, cattle were run through a race and held securely in a crush so that accurate measurement readings could take place and to comply with the farm health and safety regulations. Abattoir feedback was obtained via email either the same day or 24 hours post-slaughter. The cattle sent to slaughter in this study were classified using automated grading techniques according to the 15-point EUROP carcase classification grid. This grid differs slightly to the grid used in the previous study as it splits each fat and conformation category into 3 bands (-, =, +) in order to allow for a more enhanced and detailed carcase classification and more accurate payment to the farmer (MLCSL, 2009; Anglo Beef Producers (ABP), 2017). The figure below shows the 15-point classification grid, an example of the penalties and premiums being paid to the famer (in pence per kg) according to final carcase classification achieved, and subsequently how the UK premium classes have been chosen for this study:

Fat	1-	1=	1+	2-	2=	2+	3-	3=	3+	4-	4=	4+	5-	5=	5+
Conf.															
E+	-10	-10	-10	5	15	35	35	35	35	35	35	-15	-30	-35	-40
E=	-15	-15	-15	5	15	30	30	30	30	30	30	-15	-30	-35	-40
E-	-20	-20	-20	5	15	25	25	25	25	25	25	-15	-30	-35	-40
U+	-25	-25	-25	5	15	20	20	20	20	20	20	-15	-30	-35	-40
U=	-30	-30	-30	5	15	15	15	15	15	15	15	-15	-30	-35	-40
U-	-35	-35	-35	5	10	10	10	10	10	10	10	-15	-30	-35	-40
R+	-40	-40	-40	-5	-5	5	5	5	5	5	5	-15	-30	-35	-40
R=	-60	-50	-40	-10	-10	Base	Base	Base	Base	Base	Base	-15	-30	-35	-40
R-	-70	-60	-50	-15	-15	-5	Base	Base	Base	Base	-5	-15	-30	-35	-40
O+	-80	-70	-60	-20	-20	-15	-15	-15	-15	-15	-15	-25	-55	-55	-65
O=	-90	-80	-70	-40	-40	-30	-30	-30	-30	-30	-30	-50	-75	-75	-75
O-	-100	-90	-80	-60	-60	-45	-45	-45	-45	-45	-45	-70	-110	-110	-110
P+	-150	-150	-150	-80	-80	-60	-60	-60	-60	-60	-60	-90	-110	-110	-110
P=	-150	-150	-150	-90	-90	-80	-80	-80	-80	-80	-80	-100	-110	-110	-110
P-	-150	-150	-150	-100	-100	-100	-100	-100	-100	-100	-100	-120	-160	-160	-160

Figure 6.1: The 15 point EUROP carcase classification grid

Source: Adapted from Genesure Ltd (2015).

It can be seen from Figure 6.1 above that the 15 point carcase classification grid is virtually identical to the original EUROP carcase classification grid used in the previous study, in terms of which grades are classed as UK premium and which fall outside this range. For the purposes of this study, any grade which delivers a premium over the baseline shall be classed as a UK premium carcase classification (in this case, the green area highlighted in the figure above) and anything which delivers the baseline price or incurs a penalty is not assigned as a UK premium classification (the yellow and red areas indicated in figure 6.1 above) in order to focus solely on farmers achieving the highest possible monetary reward for their carcases. Data were analysed using IBM SPSS Statistics software version 22 and using binary logistic regression modelling procedures developed in chapter 5.

6.3 RESULTS

The results from the statistical analysis are detailed below. To begin with, descriptive statistics from the study population are displayed, giving an overview of the number of animals within each breed and gender, as well as the percentages achieving a UK premium classification. Following on, the binary logistic regression model created in the previous chapter is then run to see how well it can be applied to a group of standard commercial UK beef cattle. Further analysis comparing specific breeds is then conducted using chi square statistical methods.

6.3.1. Study sample descriptive statistics

Table 6.1 below shows the descriptive statistics of the study sample population, detailing the number of animals within each breed and gender, and the percentage within each of these categories that achieved a desired UK premium carcase classification (highlighted as the green section in figure 6.1 above). Table 6.2 then goes on to show the average measurements according to breed and gender for pelvis height and width and the three fat measurements taken from cattle prior to slaughter. These tables allow for a good overview of how the study sample is split, the numbers within each breed category and the average measurements for each gender.

Table 6.1. Number and percentage of cattle within each breed and gender that achieved a UK premium classification

Breed	Gender	Met UK Premium *n* (relative % within variable)	Did not meet UK Premium *n* (relative % within variable)
Limousin and Limousin Cross	Steer	14	10
	Heifer	13	11
	Total	**27 (56.25%)**	**21 (43.75%)**
Aberdeen Angus and Aberdeen Angus Cross	Steer	2	15
	Heifer	0	2
	Total	**2 (10.5%)**	**17 (89.5%)**
Charolais and Charolais Cross	Steer	16	11
	Heifer	2	5
	Total	**18 (52.9%)**	**16 (47.1%)**
Simmental and Other	Steer	7	5
	Heifer	2	5
	Total	**9 (47.4%)**	**10 (52.6%)**
Total Steers		39 (48.75%)	41 (51.25%)
Total Heifers		17 (42.5%)	23 (57.5%)
Overall Total		**56 (46.7%)**	**64 (53.3%)**

Table 6.2. Means and ranges of the five measurements taken from live cattle, grouped according to breed and gender

Breed	Measurement	Range	Range (Steers)	Range (Heifers)	Mean	Mean (Steers)	Mean (Heifers)
Limousin	Pelvis Height	23	21	16	143.5	145.4	141.7
	Pelvis Width	18	17	15	51.7	52.8	50.4
	10th Rib Fat Point	7	7	5	6.0	6.9	5.7
	12th Rib Fat Point	10	10	3	5.5	5.96	5.0
	P8 Fat Point	4	4	4	5.6	5.92	5.3
Charolais	Pelvis Height	21	21	8	145.9	147.3	140.3
	Pelvis Width	16	12	12	52.2	52.7	49.9
	10th Rib Fat Point	11	11	3	6.7	7.0	5.3
	12th Rib Fat Point	10	10	3	6.0	6.3	4.9
	P8 Fat Point	4	4	4	5.5	5.5	5.6
Aberdeen Angus	Pelvis Height	13	13	6	142.6	142.9	140
	Pelvis Width	13	12	7	50.8	51.1	48.5
	10th Rib Fat Point	4	4	1	5.9	6.1	4.5
	12th Rib Fat Point	5	5	1	6.0	6.0	5.5
	P8 Fat Point	4	4	3	5.4	5.4	5.5
Simmental/Other	Pelvis Height	44	15	42	146.3	145.5	147.8
	Pelvis Width	17	12	14	52.7	53.5	50.8
	10th Rib Fat Point	5	4	3	6.3	6.5	6.0
	12th Rib Fat Point	11	4	11	6.1	6.0	6.2
	P8 Fat Point	4	3	4	5.6	5.5	5.7

A chi-square test was then run to see whether either breed or gender had a significant association with UK premium carcase classification. The results from the chi square test for breed shows that there is a significant association between the breed of cattle at whether or not the carcase met a UK premium classification ($P = 0.005$). When a chi-square test for gender and UK premium carcase classification is conducted, it is seen that in this study, gender does not have significant association with whether or not a carcase is classified as UK premium ($P > 0.05$). This means that breed could therefore be entered as an independent variable alongside the live animal measurements into the final binary logistic regression model.

Basic descriptive statistical analysis was then run to find the mode, median, lower and upper quartiles associated with each of the 5 live animal measurements that were taken, in order to inform specific measurement ranges for this particular batch of cattle, using the same grouping procedure for the logistic regression model as detailed in the previous chapter. The results from this analysis are shown in table 6.3:

Table 6.3. Basic descriptive statistics of the 5 live animal measurements taken from 120 commercial UK beef cattle

Measurement	Mode	Median	Mean	Lower Quartile	Upper Quartile
Pelvis Height	140.0	143.5	144.2	140.0	148.0
Pelvis Width	50.0	52.0	51.8	49.0	54.0
10^{th} Rib Fat Point Reading	5.0	6.0	6.3	5.0	7.0
12^{th} Rib Fat Point Reading	5.0	5.0	5.8	4.0	7.0
P8 Fat Point Reading	5.0	5.0	5.6	5.0	7.0

6.3.2. Correlation analysis

A correlation analysis was then conducted with the five measurements just to ensure that should any measurements within this particular study correlate, that only one of the pair would be entered into the binary logistic regression model. The results from the correlation matrix are shown below:

Table 6.4. Correlation analysis results between the 5 live animal measurements

	Pelvis Height	**Pelvis Width**	**10th Rib**	**12th Rib**
Pelvis Width	0.41			
10th Rib	0.00	0.09		
12th Rib	0.11	0.01	0.51	
P8 Point	0.00	0.01	0.35	0.37

It can be seen from table 6.4 above that a very slight relationship (>0.5) was seen between the 10th and 12th rib fat point readings taken from the commercial beef cattle in this study. This was taken into account when entering the measurements into the binary logistic regression analysis.

6.3.3. Binary logistic regression analysis

Based on the preliminary statistical analysis from the previous study, each measurement was then divided into quartiles (for pelvis height and width) or into 3 or 4 fat levels (for the ultrasonic fat measurements) depending on spread of data. The specific measurement categories and number of cattle within each group are shown in table 6.5 below:

Table 6.5. Measurement categories for binary logistic regression analysis

Measurement	Category	Number of Cattle
Pelvis Height	Short 134 – 140cm	38
	Medium 141 – 144cm	26
	Tall 145 – 148cm	27
	Very Tall 149 – 157cm	29
Pelvis Width	Short 42 – 49cm	33
	Medium 50 – 52cm	36
	Wide 53 – 54cm	26
	Very Wide 55 – 62cm	25
10th Rib Fat Point Reading	Low 4-5mm	50
	Medium 6-7 mm	45
	High 7-15mm	25
12th Rib Fat Point Reading	Low 4mm	32
	Medium 5-6mm	49
	High 7-15mm	39
P8 Fat Point Reading	Low 4mm	29
	Medium 5mm	37
	High 6mm	19
	Very High 7-8mm	35

All possible measurement combinations along with the coded breed were then entered into a binary logistic regression analysis, taking into account the slight correlation between 10th rib and 12th rib fat point readings, meaning that they were never entered into the same model to prevent multi-collinearity, which reduced each model down to combinations of four or less measurements. After running all possible combinations of measurements, it was found that pelvis width and 12th rib fat point gave the model with the greatest predictive power and an overall significance of P = 0.018, see table 6.6 below:

Table 6.6. Output from the binary logistic regression analysis

Measurement	**Number** ***n***	**Level**	**Significance**	**Odds Ratio**	**95% CI**
		Overall Model Significance: 0.018			
Constant		-	0.363	0.555	-
Pelvis Width (Short) Reference	33	42-49cm	-	-	-
Pelvis Width (Medium)	36	50-52cm	0.731	1.206	0.415-3.507
Pelvis Width (Wide)	26	53-54cm	0.813	1.152	0.358-3.706
Pelvis Width (Very Wide)	25	55-62cm	0.167	2.251	0.711-7.124
12th Rib Fat Point (Low) Reference	32	-	-	-	-
12th Rib Fat Point (Medium)	49	5-6mm	0.190	1.907	0.726-5.010
12th Rib Fat Point (High)	39	7-15mm	0.365	1.652	0.558-4.888

Breed	34	Charolais (Reference)	-	-	-
	48	Limousin	0.723	1.183	0.467-2.999
	19	Aberdeen Angus	0.008	0.111	0.022-0.571
	19	Simmental and Other	0.722	0.808	0.250-2.615

6.3.4. Model Testing

When compared to the null model, the predictive power of the model with breed and the 2 live measurements included above went from 53.3% up to 66.7%. Table 6.7 shows the true and false positive and negative results produced from the model:

Table 6.7. True and false positive and negative results produced from the binary logistic regression analysis linking four live-animal measurements to UK premium carcase classification

	Predicted: Didn't Meet UK Premium	Predicted: Met UK Premium
Observed Didn't Meet UK Premium	39 (TN)	25 (FP)
Observed Met UK Premium	15 (FN)	41 (TP)
Accuracy (Overall % correctly predicted by the model	66.7%	

The following equations were then done to assess the sensitivity and specificity of the model:

Sensitivity = TP / (TP + FN) = 73.2%

Specificity = TN / (FP + TN) = 60.9%

Positive Predictive Value = TP / (TP + FP) = 62.1 %

Negative Predictive Value = TN / (TN + FN) = 72.2%

It can be seen from the above that the model had a high sensitivity of 73.2% which meant that it was able to correctly identify those cattle which meet UK premium almost three quarters of the time. However, the negative predictive value at 72.2% meant that cattle identified to not meet a UK premium class actually didn’t 72.2% of the time. So although the model was far better at actually identifying cattle which met, the probability that cattle identified as not meeting and them actually not meeting was greater than the positive predictive value.

When comparing this model to the one from the previous analysis, it can be seen that in regards to sensitivity, this model was far better at correctly identifying those cattle which meet UK premium (sensitivity of 73.2% vs. 54.6%). In order for cattle to have the greatest chance of meeting a UK premium classification, they had to be of limousin breed, have a pelvis which measured between 55 and 62 centimetres and have a 12^{th} rib fat point reading of 5-6mm. However, in regards to whether cattle predicted to meet UK premium actually did, the positive predictive value was much lower in this study than in the previous one (62.1% vs 80%). This could be because of the increased sample size and wider range of breeds being analysed, resulting in it being more difficult to accurately predict them meeting UK premium. This is again reflected when looking at the negative predictive values for both studies, as it was much higher in the previous study (82.1%). Again this could be due to the wider range of breeds making it harder to accurately predict which cattle would not make the premium. Specificity for this study was much lower (60.9% compared to 93.8%), which meant the model wasn’t that good at identifying cattle which did not meet UK premium. These percentages could potentially be improved in further research by having large enough sample sizes that individual models for each breed could be created, thus making for a more accurate and valid tool for farmers to use on their own cattle.

6.4 DISCUSSION

The overall aim of this study was to take the model of 5 measurements created from the previous study and apply it to a far larger, more commercial sample size, whilst seeing whether the breed of cattle played a part in whether or not an animal would meet a UK premium carcase classification. Applying the model to 120 24-36 month old commercial beef cattle from a farm in North Yorkshire reduced the model down even more to just two live-animal measurements (pelvis width and 12th rib fat point reading) in combination with breed to produce a significant model with the greatest predictive power, increasing from the null model with a power of 53.3% to 66.7%. The reduction of live-animal measurements from five to two (plus breed) was a benefit in that this means that the model is even easier, less labour-intensive and time consuming to apply and use on-farm in order to determine whether a beast is suitable for slaughter or not.

The sample used in this study was shown to be highly representative of current UK statistics in the percentage of cattle meeting a UK premium class. In 2016, 51.5% of prime beef carcases in the UK met target specification (identified to match up with the 15-point scale used in this study) (AHDB, 2016a) and it was seen from this study that 46.7% of the sample population met a UK premium carcase classification. A wide range of commercial beef cattle were used, with breed identified, again to mimic and be representative of the current UK beef industry. Interestingly, it was seen from the chi square test performed that there is no association seen between gender and outcome. This is in contrast to research by Craigie et al. (2013) who found that carcases from beef steers achieved higher conformation scores at slaughter. In regards to the chi square test performed between breed and UK Premium outcome, a significant association between the breed and whether or not they met a UK premium carcase classification was observed (P = 0.005), concurring with research which suggests that different breeds have different growth rates, carcase quality, fat and conformation measurements (Avilez et al., 2015). However, research by Fraser et al. (2009) suggests that carcase conformation scores for two different traditional and continental breeds (Welsh black and Charolais crosses) were actually quite similar, although the genotype did have an effect on growth rates prior to slaughter, thus indicating that breed may have an effect on outcome based on the system cattle are raised and finished on – with more intensive systems better for continental crosses. This could explain why an association was seen between breed and outcome of the cattle in this study, as they had all been raised on different systems across the UK, yet all finished intensively on a cereal-based diet prior to slaughter.

It is seen that Limousin cattle were almost twice as likely to achieve a desired class (OR = 1.183) although this was not significant (P = 0.723) while Aberdeen Angus cattle were significantly less likely to meet a UK premium class (P = 0.008). This could be because the intramuscular fat levels between these two breeds are shown to differ, with Angus cattle having far higher levels of intramuscular fat (Bonnet et al., 2007) and greater fat depth (Pitchford et al., 2002) and thus making them less suitable for today's market specification where higher fat levels are less desirable. However, this was not reflected in study, as when looking at table 6.2 it can be seen that the average fat depths across the P8 point and 10^{th} and 12^{th} rib fat readings for Angus cattle were not significantly different to those of the cattle from other breeds. This could potentially be because all cattle breeds were finished on the same cereal-based system, although Aberdeen Angus cattle did not have ad lib silage, unlike the other breeds, which could therefore account for the finding in this study.

In contrast to the research by Bonnet et al. (2007) and Pitchford et al. (2002), Warren et al. (2008) found that the breed of cattle had little effect on meat quality and that sensory scores between the meat of two breeds (Aberdeen Angus crosses and Holstein Friesian crosses) were very similar, although any differences were in favour of the Angus crosses. This could simply be because the Angus crosses are more of a beef-breed type than Holstein crosses, thus inevitably being more desirable and suitable for the UK beef market and so scoring better. Furthermore, the Simmental and Other breeds category were also shown in the study to have a reduced chance of meeting a UK premium class than Limousin cattle or Charolais (although not significant) and with half of this category made up of "traditional breeds" such as the British Shorthorn, this indicates that it was the continental and continental crossbreeds which are far more suited to the current UK market specification, with the more muscular, leaner continental cattle achieving the better carcase classifications.

In terms of the ultrasonic 12^{th} rib fat point reading, it is seen that cattle of a medium fat depth (5-6mm) were more likely to meet a UK premium carcase classification, although this was not significant. This could partially be attributed to the high proportion of steers used within the study as it is said that steer carcases have a lower fat density than heifers and that steer carcases are more suited to supermarket specification while heifers are often used for more specialist markets (Venkata Reddy et al., 2015) that require carcases of greater fat levels, such as butchers. However, when looking at the average fat depth readings across the three measurement sites, it can be seen from table 6.2 that limousin, charolais and angus steers actually had higher average fat depth readings than heifers. This is in line with research by Steen and Kilpatrick (1995) who found that heavier steer carcases had greater fat levels. This could again be down to the method of finishing, with the intensive finishing system in the study allowing for a greater accumulation of fat across the rib and rump regions in the steers.

In regards to pelvis width proving to be one of the measurements best able to predict whether or not cattle achieve a UK premium carcase classification, this again could be directly related to breed as continental cattle are larger and taller than traditional breeds (such as the Aberdeen Angus) and it is seen that the continental breeds were more likely to achieve a desired classification. The fact that very wide cattle (55-62cm) were up to twice as likely to meet UK premium (although not significant) concurs somewhat with Lazzaroni et al. (2007) found that the larger cattle were better in terms of the conformation class achieved.

In regards to how the measurements taken could help improve the selection of cattle for slaughter and subsequent savings through them meeting a premium classification, when looking at the null model where no measurements were applied, only 53.3% of cattle met a UK premium class. For example, if a farmer sent 100 cattle to slaughter, only 53 of these animals met a UK premium carcase classification. If the average price for a UK premium carcase in 2016 was 372.5 pence per kilogram for an animal which met UK premium, and the average carcase weight was 372.4kg (AHDB, 2017), then this means the average price the farmer received for that carcase was £1389. If only 53 of the 100 animals sent to slaughter met this price, then the farmer would ultimately receive £73, 617.

When the pelvis width, 12th rib fat point reading and breed were entered into the model, this improved the model up to 66.7%. So if a farmer used the measurements and assessed the animals prior to slaughter and 67 of the 100 cattle sent to slaughter met a UK premium class, then using the same calculations as above, the farmer would receive approximately £93,063 for those animals. This is a substantial increase of £19,446, thus demonstrating how cost-effective using the measurements prior to sending cattle to slaughter would be. Furthermore, with the cost of the Renco Lean-meter for measuring the 12th rib fat point reading being around £500 and the time taken to measure each animal being no more than two minutes (if the cattle are used to the handling facility), then the equipment and labour costs associated with taking these measurements are easily outweighed by the financial return seen when the measurements are applied. If this financial gain was adequately disseminated to farmers through the use of demonstrations, then this would help ensure that far more cattle met a UK premium classification in the future.

6.4.1 Study limitations

One of the limitations of this study was the fewer numbers of heifers to steers within the study population, with only a third of the sample being made up of heifers. This meant that it was hard to compare the sexes in regards to meeting UK premium classes as more heifers would be required for a fair comparison to be made. Fewer heifers may also have had an effect on the overall carcase classification outcomes. Research by Steen and Kilpatrick (1995) found that not only do heifers have lighter carcase weights at finishing, but cattle which finished at heavier slaughter weights have increased fat content and reduced lean, which would mean they would score higher for fat on the EUROP grid. The fact that two thirds of the study population were male could go some way to explaining why only 46.7% met UK premium. Future research into this area should include more heifers in order to provide a more balanced sample for analysis. Another limitation of the study was the limited numbers of certain breeds. For example, with only 19 Aberdeen Angus cattle in comparison with 48 Limousin cattle and 34 Charolais cattle, it makes it slightly less reliable to draw breed comparisons. Furthermore, only two of the Aberdeen Angus sample were heifers, which again highlights the need for larger samples from each breed in order to increase the usefulness and validity of the research and allow for gender comparisons to be made. Further research should look at ensuring all breed groups are of a more equal size in order for more valid comparisons between breed, gender and likelihood of achieving UK premium carcase classification to be made. The fact that cattle were sent in batches of forty was also another limitation to the research. This meant that 40 animals had to be measured prior to being loaded on to the lorry for the abattoir and this was limited by time constraints. This meant the measurements had to be taken extremely fast and so it was often difficult to ensure cattle were standing soundly in order for the measurements to be taken. However, sending cattle in groups of forty did allow for rapid abattoir feedback for analysis. In an ideal world, the measurement process would not be limited by time constraints. This would help ensure that cattle were standing soundly and not stressed as this can give inaccurate readings. Another problem with sending cattle in groups of forty was that forty animals had to be sent, regardless of whether they were deemed suitable for slaughter or not. This again could explain why only 46.7% met UK premium, as not all animals were in prime slaughter condition. However, this did allow for a wide range of carcase classifications to be analysed once received from the abattoir.

6.5 CONCLUSION

Pelvis width, 12^{th} rib fat point reading and cattle breed can be used to help predict whether or not live cattle will meet a UK premium carcase classification or not. From the sample used within this study, it is seen that wide limousin cattle with a medium twelfth rib fat point reading were the most likely to meet a UK premium carcase classification. Farmers can therefore use this finding when buying in cattle to finish in order to help give them the best chances of meeting a desired carcase classification and subsequently receiving a better premium when sent to slaughter. Furthermore, the measurements given can be taken on-farm and used alongside breed, so that farmers can assess and predict when their animals are most likely to meet the grade. This will help to reduce wastage across the UK beef industry as more cattle will be of desirable quality, increase the amount of suitable cattle carcases for market specification and ensure farmers receive the best monetary rewards possible for their animals. Further research could go on to look at creating individual models for specific breeds. This would involve larger sample sizes for each breed used, with an even amount of steers and heifers. Breed-specific models could potentially provide a more accurate, valid and reliable method of assessing whether cattle are ready for slaughter and will meet a UK premium carcase classification as they would help eliminate breed differences which could have limited this study.

CHAPTER 7. THE PAST, PRESENT AND FUTURE OF LIVE-ANIMAL ASSESSMENT AND CARCASE CLASSIFICATION IN THE UK

7.1. INTRODUCTION

The need for increasing food production to suit a growing population by 2050 is a necessity (Food and Agriculture Organisation (FAO), 2009). This means that meat produced has to be efficient and sustainable, which may inevitably lead to a loss of quality through a faster, more intensive production. With less than fifty percent of all cattle carcases graded at the abattoir meeting UK premium classifications (AHDB, 2016a), this is causing significant financial losses and wastage to the beef industry. Current methods of live animal assessment and selection for slaughter haven't really changed in over 200 years, highlighting the need for a more updated and objective approach to suit the systems and cattle seen today, in order to produce meat more efficiently to meet the demands of population increase. The overall aim of this research project was to see whether a set of morphometric and live animals measurements taken from cattle prior to slaughter could be used to predict the likelihood of whether or not the carcase would achieve a UK premium classification according to the current EUROP system of beef carcase classification.

It was found when looking at the history of live animal assessment and beef carcase classification in Chapter 2 that the way farmers and assessors select animals for slaughter has not really changed much within the past two hundred years and that methods such as visual assessment and manual handling techniques are subjective and could be one of the reasons why so many cattle are failing to meet a valuable carcase classification. The ability to accurately select animals in prime condition for slaughter would also reduce the risk of over-fattening, thus reducing the amount of feed used to finish the animal and also reducing the need for fat-trimming of the carcase, therefore reducing wastage and penalties across the UK beef industry. Following on from this, a review of a set a set of fifteen different ultrasonic and external fat and morphometric measurements used in previous scientific studies and research, taking into account the practicality of using them in a working environment as well as analysing the points of reference to use when taking each measurement. It was found that some of these measurements were already being used in pre-slaughter selection of cattle in other countries, thus adding validity to their inclusion within this research project. Chapter 4 identified the samples used in the following studies and gave a detailed account of how to take each of the measurements from live cattle in order to ensure each measurement was as accurate and as repeatable as possible, based on previous research. In the initial questionnaire study, it was found that farmers do not necessarily take up live-animal selection aids well, particularly amongst the older generation. They also learnt best through experience and that physically interacting with both the live cattle and then the carcases aided their ability in live animal selection much better than learning from a manual. This meant that any tool created to assist in objective live animal selection and assessment needed to be something they themselves could apply to their own cattle, and that they could see the benefit of using such a tool. Through rigorous preliminary statistical analysis procedures, the original fifteen measurements discussed in Chapter 4 were reduced down to nine to be taken forward into the initial binary logistic regression model linking live animal measurements to UK premium carcase classification in Chapter 5. Through a binary logistic regression analysis, these nine measurements were further reduced down to five (pelvis height and width, 10^{th} rib, 12^{th} rib and P8 fat points), which when combined in the model, improved the predictive power of the model from 69% (null) up to 85.9% and indicated that taller, wider and slightly fatter cattle were more likely to meet a UK premium carcase classification. This therefore provided a set of measurements taken from live cattle could be used to help predict the likelihood of achieving a premium carcase classification. Finally, the model created was taken even further and applied to a more commercial sample of beef cattle in order to see whether it could be applied in a real-world setting. Interestingly, it was found that when breed was entered into the model, the best model produced only required pelvis width and 12th rib fat point reading and it was found that wide limousin cattle with a medium twelfth rib fat point reading were the most likely to meet a UK premium carcase classification. Therefore, the final aim of this closing chapter was to see what the future for the current beef carcase classification system holds; how this will affect selection for slaughter in live cattle and how inevitable population growth and the implications of Brexit may influence changes to the current EUROP carcase classification grid and subsequently the breeds of cattle seen within the UK.

7.2. THE IMPLICATIONS OF BREXIT ON THE EUROP SYSTEM OF BOVINE CARCASE CLASSIFICATION AND LIVE ANIMAL ASSESSMENT IN THE UK

According to the United Nations (2017), the global population is set to increase to 9.8 billion by 2050 and 11.2 billion by 2100 and this results in greater demands for food across the world. The current beef carcase classification system has been in practice within the UK since the late 1970's, with the role of conformation and fat class in carcase grading going back even further (see chapter 2), so it could be said to be outdated and in need of renewal (Yeomans, 2009), such as focusing more on the final "eating quality" aspect to assess and grade the quality of beef carcases, although this is currently impossible to predict accurately due to individual preferences in meat characteristics. It could also be said that more farmers would get their cattle to meet the grade if the system was more up-to-date and relevant to the particular types of beef cattle seen within the UK industry today.

On the 23rd of June 2016, it was voted that the UK should leave the EU, with this scheduled to take effect from the 29th of March 2019 (Hunt and Wheeler, 2017), although there is currently no suggestion that the UK will move to a new system of beef carcase classification and grading. However, the AHDB have called for industry input and views on the EUROP system, indicating that there is the potential possibility for a change and that the implementation of Brexit means that consideration could be given should a better way to classify and grade bovine carcases be found (AHDB, 2016b). There is a view that the system used in the UK should be more like that used in America and should be based more on retailer and consumer demands with premiums given for yield and meat quality (Ridler, 2017), rather than focusing on the conformation and fat levels of the carcase as a whole.

There are currently eight grades associated with beef quality used in America (Ferrier and Lamb, 2007), applicable to both steer and heifer carcases. These grades outlined by Tatum (2007) are: Prime, Choice, Select, Standard, Commercial, Utility, Cutter and Canner. Retail trade in cuts of beef tends to be limited to the Prime, Choice, Select and Standard grades only, with Prime grades tending to go towards the upscale restaurant market (Ferrier and Lamb, 2007). Beef quality grades are determined through the combining of degree of marbling and maturity of a carcase. These beef quality grades are then used alongside yield grades ranging from 1 to 5 (Polkinghorne and Thompson, 2010). Bull beef is not graded using the USDA system, cow beef is not eligible for the Prime grade and bullock beef is also graded differently from that of steer and heifer, with the grades Commercial, Cutter and Canner not being applicable to beef from those animals. Table 7.1 below displays a clear representation of the eight beef quality grades used in America and the type of animal that each grade can be assigned to:

Table 7.1: Application of USDA Beef Quality Grades to Cattle

	Prime	Choice	Select	Standard	Commercial	Utility	Cutter	Canner
Heifer	*	*	*	*	*	*	*	*
Steer	*	*	*	*	*	*	*	*
Bullock	*	*	*	*	N/A	*	N/A	N/A
Cow	N/A	*	*	*	*	*	*	*
Bull	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

* - Applicable to animal N/A – Not applicable

Source: Adapted from Tatum (2007); Polkinghorne and Thompson (2010)

Degree of marbling is then also assigned one of nine grades (devoid, traces, slight, small, modest, moderate, slightly abundant, moderately abundant, abundant and very abundant) (Parish et al., 2009), all of which can be seen in Table 7.2 below. The standards for the degree of marbling are set through the use of photographs (Tatum, 2007; Polkinghorne and Thompson, 2010). The carcase is then given a maturity level ranging from A through to E based on the approximate age of the animal at slaughter. The maturity level "A" is for the youngest animals (9-30 months) whereas maturity level "E" is for the oldest animals (>96 months) (Tatum, 2007). Higher quality grade carcases are identified through better marbling grades at a younger maturity level, for example, to get a Prime grade carcase, there needs to be a minimum of slightly abundant marbling within the maturity level A, increasing to moderately abundant marbling at maturity level B. This demonstrates that as the maturity level (age of animal at slaughter) increases, marbling grade has to increase to compensate for this in order for the carcase to maintain a Prime grade. Table 7.2 below is an adaptation of the USDA beef grading system table, taking into account the relationship between maturity levels, marbling and carcase quality grade:

Table 7.2: The Relationship between Carcase Quality Grade, Marbling and Maturity

	Maturity Level (Months)				
Degrees of Marbling	**A** (9-30)	**B** (30-42)	**C** (42-72)	**D** (72-96)	**E** (>96)
Very Abundant					
Abundant					
Moderately Abundant				Commercial	
Slightly Abundant	Prime				
Moderate					
Modest	Choice				
Small					
Slight	Select			Utility	
Traces					
Devoid	Standard			Cutter	

Source: Adapted from Tatum (2007); Parish et al. (2009).

Yield grades are then used to estimate beef carcase cutability, defined by Tatum (2007) as:

"The combined yield of closely trimmed, boneless retail cuts from the round, loin, rib and chuck"

Yield grades are determined through use of a regression equation, taking into account external fat; heart, kidney and pelvic fat; area of the quartered *M. longissimus dorsi* and the hot carcass weight (Tatum, 2007). External fat is usually analysed over the ribeye region, but can be adjusted to account for excess fat in other regions. The carcase is then graded on a scale from 1 to 5, with grade 1 having the highest percentage of retail cuts (>52.3%) and therefore being the most desirable yield grade whereas grade 5 has the lowest percentage of retail cuts (<45.4) and is excessively fatty (Parish et al., 2009).

This is an example of a system the UK could potentially switch to when grading and classifying cattle carcases, with the focus more on eating quality rather than fat level and shape. However, there are some strong arguments for not changing the current carcase classification system. A downside to this system based around eating quality and final product is that it is of more interest to retailers than to the farmers themselves. This is because there is currently still be no way to decide in live cattle whether or not they would be of good eating quality to the consumer. This highlights the need for a piece of equipment, such as a full body scanner, which could scan or assess the live animal in the same way that a human or video image analysis assesses a carcase in order to classify it, although the feasibility of small-scale beef farmers in owning such a scanner in the future is questionable.

Secondly, with uptake of new ideas and practices notoriously difficult to get farmers utilising (see chapter 3), the fact that the current system is widely accepted and understood by farmers means that changing it could cause a loss of trust and clarity across the sector (Ridler, 2017). It is seen from the questionnaire in chapter 3 that farmers do know what sort of carcase classifications they should be aiming for and how the grading system works, they just need better assistance in getting their cattle to meet the UK premium categories. This then leads on to the idea that the UK should maintain the EUROP grid of bovine carcase classification, but more focus and emphasis is then placed on "getting it right" i.e. getting more cattle to meet UK premium carcase classification. This is where more objective methods of pre-slaughter selection and assessment would come into play, with greater emphasis on measuring and monitoring the growth of their cattle (based on the findings from chapter 6) in order to help ensure they meet a UK premium class and that they are not "over-finished".

If the UK system of beef carcase classification does go on to follow that of the United States of America and results in grading beef carcases based on yield and eating quality (such as marbling and maturity), this then presents a further problem: how do farmers select their animals for slaughter? Ensuring cattle are of a premium marbling grade while alive will be even more difficult to ascertain than when currently trying to assess their conformation and fat levels and predicting their eating quality would happen at the abattoir, post-slaughter. There are currently guides available, such as the Better Returns Programme, to help farmers assess when their animals are ready for slaughter based on visual and manual assessments of conformation and fat level in the live animal, with this being linked to the conformation and fat class assigned to the carcase. It is known based on these guides for example, that the more convex the animal, the more likely it is to be of better conformation. However, if the system post-Brexit is based solely on eating quality and meat yield alone, how are farmers going to assess this in the live animals and how will they select their animals for slaughter? Again this raises the need for some form of real-time scanner or computer analysis system (should an eating quality classification system be adopted) which can scan cattle prior to slaughter, in order to help determine marbling and maturity score.

One final note to make about the impact of Brexit on carcase classification and pre-slaughter assessment is what will happen to exportation and those cattle that meet the current "export" regions of the EUROP carcase classification grid (E2, U+2, -U2). Export levels currently sit at 15-17% of all beef produced, amounting to 100,000-120,000 tonnes with over 90% of these exports going to other EU countries in 2015 at a value of £342 million (AHDB, 2016b). Carcases and cuts that meet these classes are currently exported as they receive a higher value overseas than here in the UK and so those categories on the EUROP grid also receive premium prices when farmers have cattle which meet these grades (AHDB, 2016b). However, with the implementation of Brexit, if the UK does not negotiate free access to the

Single Market (in which little would change in terms of import and export products), beef from the UK shipped to the EU could be subject to EU import tariffs where once a quota is met the tariff reverts to a standard rate (Quality Meat Scotland, 2017). This could potentially impact the whole UK beef sector, with reduced premiums for cattle carcases suitable for export, so therefore it may be even more essential for farmers to be able to objectively and accurately determine when their live cattle are going to hit UK premium classifications, so they can choose whether or not to aim for these specific export classes. On the other hand, this reduction in export could lead to a greater uptake in these once-exported cuts within the UK market, and cuts such as the silver side would regain popularity and start appearing more frequently on supermarket shelves. This would mean that the carcases and cuts once exported to overseas markets would become more valuable within the UK beef sector, thus potentially resulting in these classifications becoming worth a higher premium, a benefit for farmers producing cattle which cull out at these classes.

Regardless of the outcome of Brexit on the current carcase classification system and pre-slaughter assessment of cattle, it is of benefit to the industry as a whole for farmers to be able to determine readiness for slaughter in their beef cattle. There are many reasons why less than half of beef cattle within the UK could be failing to meet a premium carcase classification. One of these reasons is that native breeds do not generally classify out as well as continental breeds and with a lot of the land in the UK unsuitable for large continental breeds, traditional ones still make up a high proportion of the national kill. Traditional breeds often don’t classify as well because they lay down fat earlier on in life (in order to suit harsh climates) and therefore are often over-finished when it comes to slaughter (Greiner, 2009). This means that they can be classed as over-fat and, with less muscle development than the continental breeds, also end up with a poorer conformation class. Secondly, market price plays a major role in when farmers send their cattle to slaughter. If market price is low, farmers will keep their animals back longer, waiting for the price to rise again. This can lead to cattle being over-finished and therefore not make a UK premium classification. This can also work in reverse. When the market price is high due to beef shortages, farmers may send their cattle too soon, resulting in significantly lower conformation and fat classes and consequently a poorer return per animal. If farmers could more accurately predict when their cattle were going to be ready and in prime slaughter condition, then this would help them plan for rises and falls in market price, ensuring the highest possible return. However, the only way the use of live-animal measurements (such as the 10th rib fat point and pelvis height) to help predict likelihood of meeting a UK premium carcase classification and subsequently improving the percentage of cattle achieving these categories across the UK beef industry is to improve farmer openness and uptake in new and novel ideas.

7.3. IMPROVING FARMER UPTAKE IN LIVE ANIMAL ASSESSMENT METHODS

It is seen from chapter 3 that new and novel ideas are not necessarily readily adopted by farmers, particularly within the elder generation and therefore in order for live animal measurements associated with eventual carcase outcome (such as 12th rib fat point reading and pelvis width found in chapter 6) to be used across the industry, there needs to be ways to engage farmers in these new methods of pre-slaughter assessment. It is seen from the results in chapter 3 that farmers learn and adopt ideas far better if they are physically performing a task, rather than just learning from a manual.

It is argued by Oliver et al. (2012) that in order for farmers to fully engage with an idea, three rationales need to be met. The first of these is inclusiveness: in that farmers feel that they have the right to influence the process that may have an impact on them and that they are fully aware of the process itself, but not yet actively engaged. For example, in the future farmers may be aware of the fact that specific live animal measurements can help predict likelihood of meeting a UK premium classification, but that they have the right to choose whether or not to adopt it yet. The second of the rationales proposed by Oliver et al. (2012) is acceptability. This is where farmers see the benefit of their engagement with a particular idea and feel that they are actively involved with the creation of an idea which could benefit their industry as a whole. This will make them far more likely to engage with that new idea. For example, with the commercial beef finishing farm used in chapter 6, the fact that the farm was partaking and included in research which could improve pre-slaughter selection in beef cattle for the UK beef industry meant that they were far more open to research taking place on the farm as well as using the eventual live animal measurements at the end of the study. Finally, the third rationale is effectiveness. If farmers see the benefit of using and applying the process (such as live animal measurement and the resultant effect of more cattle achieving UK premium carcase classification) then they are far more likely to use that idea.

This trio of rationales could form the fundamental basis for disseminating the use of live animal measurements as a predictor of the likelihood of meeting UK premium carcase classifications across the UK. With farmers given the option to trial the measurements themselves, (perhaps after demonstrations as it was found in chapter 3 that the live-to-dead demonstrations were the most effective and viewed most positively by the farmers), they then feel they are an active part of the development process and subsequently more likely to apply the research on-farm. The rapid uptake of a beneficial system to assess cattle for slaughter suitability is of even more importance with global population increase and the need to increase food production. With an objective pre-slaughter selection and assessment method in place, more cattle will hit market specification, less feed will be used over-finishing cattle, less wastage will be seen in the carcase trimming process and therefore the entire industry can be streamlined into providing more food for the ever-increasing population.

However, if more (or all) cattle did meet market specification and achieve UK premium classifications, then all carcases would result in the same pay out. With a reduction in penalties or fines being paid back to the abattoir through over-fat/lean/poorly conformed cattle, then the overall price of beef carcases would fall and there would be a surplus of supermarket-quality meat which would decrease in value, meaning that farmers may end up actually losing money if all their cattle met the desired grades. This again could potentially lead to a switch in how carcases are classified, with more focus being on final eating quality rather than fat level and conformation.

7.4. POPULATION GROWTH AND BEEF CATTLE PRODUCTION IN THE UK

In regards to UK beef production, this could cause a shift in the types and breeds of cattle seen across the UK. This shift could go one of two ways; either with cattle being grazed more extensively on less favourable areas, thus leaving more prime land needed for crop growth or being taken off the land and subsequently being reared more intensively, similar to American feedlot systems. Therefore the effect on pre-slaughter selection and carcase classification need to be assessed:

With more prime grazing land needed for crop growth for human food consumption, this could lead to beef cattle being grazed more extensively on less favourable areas of tougher climatic conditions, such as more hilly and mountainous regions (Aby et al., 2012). This means that the continental breeds seen in beef production today could potentially be phased out, resulting in a return of the smaller, harder, more traditional breeds of cattle that are better adapted to grazing off these less favourable regions. In reference to the findings of the study in chapter 6, this means that there will be less chance of these types of beef cattle achieving UK premium carcase classifications. The results from the binary logistic regression analysis show that continental breeds such as the Limousin and their crosses are almost twice as likely to achieve a UK premium class whereas a traditional breed like the Aberdeen Angus was less likely to achieve a UK premium class. However, it is seen that there were far fewer Angus cattle in the study sample population than there were than either Limousin or Charolais, which could go some way to explaining why such a difference between the continental and traditional breeds was seen. Although, the study in chapter 6 also showed that cattle wider in the pelvis are also more likely to meet the grade, this yet again doesn't bode well for the traditional breeds and eventual carcase classification. A potential solution for this, should a shift in this direction could mean that beef x beef crossbreeds (such as Limousin-angus crosses) or more three-way crosses (to take surplus from the dairy industry) may become necessary, in order to produce cattle which are both adapted to an extensive environment, yet still produce a good quality carcase. These crossbreeds should retain an increased performance, high production efficiency and are hardy enough to live in these areas, without any added inputs or costs, yet still have the ability to meet a UK premium carcase classification (Hansen, 2007; Aby et al., 2012). Heterosis could also then play a part in the new crossbreeds (Future Beef, 2011), which could result in cattle that actually finish faster on the rougher terrain than either one of the parent breeds.

The other possible way the UK beef industry could go in order to meet increasing demands for food due to a rising population is for even more intensive beef production than that seen today, again taking beef cattle off the land and finishing them fully indoors, in similar systems to the American feedlots. However, this would result in more land needed to grow food for these intensively reared cattle which could be used to feed the ever-expanding population. This would therefore call for a need for better ration formulation in order to ensure cattle finish faster at heavier carcase weights, as well as the use of faster finishing, more muscular and leaner types of cattle. With continental cattle breeds well known for their fast finishing rates, leaner composition and overall better conformation, as well as doing well on intensive finishing systems, it is probable that more continental breeds and crossbreeds could be seen in the future, should the UK beef industry go for greater intensification. The fact that the continental breeds (Limousin and Charolais) within the study in chapter 6 were more likely to achieve a UK premium carcase classification means that greater use of these continental breeds in the future should mean that there is an increase in the amount of premium carcases produced, thus providing more meat for growing human population.

7.5. FUTURE APPLICATIONS AND DEVELOPMENT OF RESEARCH

Following on from the relationship seen between breed and UK premium carcase classification, future research could look at comparing pure-bred cattle with crossbreeds as this distinction was not made in this project. In chapter 5 the cattle used in the study were 3-way dairy-beef crosses, meaning that identification of breed was more difficult, and the influence of the beef breed genetics in the animals may be somewhat dilute, therefore breed was factored in to the study instead, where specific identification of individual animals was much easier. In the study in chapter 6, cattle were grouped according to the main breed given on the abattoir feedback sheet, therefore meaning that, for example, pure bred Limousin cattle were grouped alongside those Limousin crossbred cattle. Increasing the sample size even further in future projects could make this a realistic possibility and valid comparisons between pure and crossbred beef breeds could be made. This would be of benefit to the industry to see whether the likelihood of achieving a UK premium carcase classification could be influenced by either pure bred or crossbred cattle and subsequently guide farms in the future in their choice of breed best suited to their finishing system and most likely to achieve a desirable carcase classification.

The fact that the carcase classification systems for both beef and sheep within the UK are very similar could mean that the use of live animal measurements in beef cattle to predict likelihood of UK premium carcase classification could also be applied to the UK sheep industry. The amount of sheep carcases meeting UK premium classifications is very similar to that of the beef industry, with a similar story in the continuing lack of carcases failing to meet desired classification over time displayed in the industry. In 2016, only 56.8% of all sheep carcases met the target sector of E,U,R and 1,2 and 3L classifications (AHDB, 2016c). The 15 measurements initially used in the first study seen in chapter 6 could be taken from live sheep prior to slaughter and the same elimination and modelling process applied. This could then potentially help to ensure that more sheep carcases meet the optimum classifications, particularly as overly fat lamb is currently a big problem within the UK sheep industry (AHDB reported that in 2016, 26.8% of sheep carcases were deemed too fat).

A further recommendation for the application of the findings of this research to the UK beef industry is that farmers should have access to both an ultrasonic fat depth reader and a height stick. The fact that the 10th rib fat point, in conjunction with pelvis height and cattle breed proves useful in helping to predict the likelihood of achieving a UK premium carcase classification means that through the purchasing of a reader and a height stick, the cost of the purchase would rapidly be made up for with the increase of beef cattle meeting desired classification at slaughter. Frequent measuring of cattle as they grow will help to pinpoint the best time to send them to slaughter, when they are in peak condition and will help to prevent over-finishing and over-fattening, thus reducing wastage in the UK beef industry.

7.6. CONCLUSION

The way we assess readiness for slaughter in beef cattle has not really changed in the past 200 years, with subjective visual and manual assessments of cattle still the primary mechanisms used to determine peak condition, resulting in less than half of all cattle carcases meeting a UK premium classification. With uptake of current assessment aids such as the Better Returns Programme relatively low across UK beef farmers, the need for a more objective means of pre-slaughter assessment in cattle has become more crucial and vital to the UK beef industry in recent years, especially in response to an increased demand for food to sustain a growing population.

The overall aim of this research project was to see if a range of live animal assessment methods taken prior to slaughter could be used to help predict whether or not that animal would achieve a UK premium carcase classification. From the research undertaken, it is clear that there is definitely the possibility for certain live animal measurements, most notably the pelvis width and 12th rib fat point reading, to be taken prior to slaughter and used in conjunction with the cattle breed in order to predict the likelihood of the carcase meeting a UK premium carcase classification. Furthermore, it was discovered that continental cattle breeds (in particular, the Limousin breed), cattle that were wider at the pelvis (between 55 and 62cm) and those with a 12th rib fat point reading of 5-6mm were more likely to achieve a desired UK premium carcase classification at slaughter. With traditional breeds such as the Aberdeen Angus being less likely to meet one of these optimum classifications, and with the likelihood of these traditional breeds being utilised more in the future due to the need to produce beef in the UK through more extensive systems thanks to the demands of global population increase, future research needs to look at improving the overall carcase conformation and fat levels of these breeds so that they meet UK premium specification, with the potential for crossbreeding with continental breeds as a solution to this problem.

Finally, the UK beef industry has to adapt to a rapidly changing world. With Brexit just around the corner and therefore the potential for the EUROP system of carcase classification to be altered or amended, alongside the need for a reduction in wastage and more food to be produced to feed an ever-expanding population, using live animal measurements for objectively assessing peak slaughter condition in beef cattle could be a vital tool not only for the future of the UK beef industry, but one that could eventually be applied across the world.

REFERENCE LIST

Aass, L. (1996) “Variation in carcass and meat quality traits and their relations to growth in dual purpose cattle”, Livestock Production Science, 46 (1), 1-12.

Aby, B.A., Aass, L., Sehested, E., Vangen, O. (2012) “Effects of changes in external production conditions on economic value traits in Continental and British cattle breeds”, Livestock Science, 105 (1-3), 80-93.

Agriculture and Horticulture Development Board (AHDB). (2008) Review of the EU carcase classification for beef and sheep [www document]. http://archive.defra.gov.uk/evidence/economics/foodfarm/reports/carcaseclassification/Full%20Version.pdf (accessed 26 October 2011).

Agriculture and Horticulture Development Board (AHDB). (2012) Agriculture and Horticulture Development Board Annual Report and Accounts 2011/2012 [www document]. http://www.official-documents.gov.uk/document/hc1213/hc02/0238/0238.pdf (accessed 10 December 2012).

Agriculture and Horticulture Development Board (AHDB). (2015) UK Yearbook 2015 Cattle [www document]. http://beefandlamb.ahdb.org.uk/wp/wp-content/uploads/2015/07/UK-Yearbook-2015-Cattle-200715.pdf (accessed 16 November 2015).

Agriculture and Horticulture Development Board (AHDB) (2016a) UK Yearbook 2016 Cattle. [www document] http://beefandlamb.ahdb.org.uk/wp-content/uploads/2016/07/UK-Yearbook-2016-Cattle-050716.pdf (accessed 5 June 2016).

Agriculture and Horticulture Development Board (AHDB). (2016b) Horizon: What might Brexit mean for UK trade in beef and lamb products [www document]. https://ahdb.org.uk/brexit/documents/BeefandLamb_bitesize.pdf (accessed 20 August 2017).

Agriculture and Horticulture Development Board (AHDB). (2016c) UK Yearbook 2016 Sheep [www document]. http://beefandlamb.ahdb.org.uk/wp-content/uploads/2016/07/UK-Yearbook-2016-Sheep-050716.pdf (accessed 20 August 2017).

Agriculture and Horticulture Development Board (AHDB) (2017) UK Yearbook 2017 Cattle. [www document] http://beefandlamb.ahdb.org.uk/wp-content/uploads/2017/07/UK-Yearbook-Cattle.pdf (accessed 28 July 2018).

Agriculture and Horticulture Development Board (AHDB) (2018) Deadweight Cattle Reports. [www document] http://beefandlamb.ahdb.org.uk/markets/deadweight-cattle-reports/ (accessed 28 July 2018).

Aiken, G.E., Rouquette JR, F.M., Miller, R.K. (2002) “Grazing treatment effects on ultrasound measures of the 12th to 13th rib fat thickness and longissimus area”, The Professional Animal Scientist, 18 (4), 368-372.

Alderson, G.L.H. (1999) “The development of a system of linear measurements to provide an assessment of type and function of beef cattle”, Animal Genetic Resources Information, 25 (no issue no.), 45-55.

Allen, P. Finnerty, N. (2001) Mechanical Grading of Beef Carcasses. Dublin: Teagasc.

Allen, R.L. (1865) in Fith Fath Images (2011). Domestic Animals: Cattle [www document]. http://fithfath-images.livejournal.com/1133.html (accessed 17 February 2015).

Alonso, J., Bahamonde, A., Villa, A., Castañón, A.R. (2007) “Morphological assessment of beef cattle according to carcass value”, Livestock Science, 107 (2-3), 265-273.

Alonso, J., Castañón, A.R., Bahamonde, A. (2013) “Support Vector Regression to predict carcass weight in advance of the slaughter”, Computers and Electronics in Agriculture, 91 (no issue no.), 116-120.

Alvarez, J., Nuthall, P. (2006) “Adoption of computer based information systems: the case of dairy farmers in Canterbury, NZ, and Florida, Uruguay”, Computers and Electronics in Agriculture, 50 (1), 48-60.

Amudavi, D.M., Khan, Z.R., Wanyama, J.M., Midega, C.A.O., Pittchar, J., Nyangau, I.M., Hassanali, A., Pickett, J.A. (2009) “Assessment of technical efficiency of farmer teachers in the uptake and dissemination of push-pull technology in Western Kenya”, Crop Production, 28 (11), 987-996.

Anderson, D.M., Tietjen, G. (1982) “Drylot shrink of cattle grazing semidesert rangeland during February, May, July and October”, Proceedings of the Western Section Meeting, American Society of Animal Science, US Department of Agriculture, Agricultural Research Service and Los Alamos National Laboratory, 7-9 July 1982, 242-245.

Anglo Beef Producers (ABP) (2017) FAQ The 15 Point Grid [www document]. https://abplivestock.com/events-dates/2016-01-24-faq-the-15-point-grid (accessed 10 July 2017).

Atta, M., El khidir, O.A. (2004) “Use of heart girth, wither height and scapuloischial length for prediction of liveweight of Nilotic sheep”, Small Ruminant Research, 55 (1-3), 233-237.

Avilez, C., Martinez, A.L., Domenech, V., Peña, F. (2015) “Effect of feeding system and breed on growth performance and carcass and meat quality traits in two continental beef breeds”, Meat Science, 107 (no issue no.) 94-103.

Ballantyne, C. (2005) “Moving student evaluation of teaching online: reporting pilot outcomes and issues with a focus on how to increase student response rate” Paper presented at the 2005 Australasian Evaluations Forum: University Learning and Reaching: Evaluating and Enhancing the Experience, University of New South Wales, Sydney, 28-29 November 2005.

Barham, B., Troxel, T.R., Jones, S.M. (2011) An Analysis of Beef Cattle Conformation. Arkansas. University of Arkansas Division of Agriculture.

Bass, J.J. (1981) “A note on the relationships between tissue depths over the 10^{th} rib and cattle carcass composition”, New Zealand Journal of Experimental Agriculture, 9 (2), 211-212.

Bene, S., Nagy, B., Nagy, L., Kiss, B., Polgár, J.P., Szabó, F. (2007) “Comparison of body measurements of beef cows of different breeds”, Archives Animal Breeding, 50 (4), 363-373.

Berg, R.T., Walters, L.E. (1983) "The Meat Animal: Changes and Challenges", Journal of Animal Science, 57 (2), 133-146.

Black, W.H., Knapp, B., Cook, A.C. (1938) "Correlation of body measurements of slaughter steers with rate and efficiency of gain and certain carcass characteristics", Journal of Agricultural Research, 56 (no issue no.) 465-472.

Blood, D.C., Studdert, V.P., Gay, C.C. (2007). Saunders Comprehensive Veterinary Dictionary (3rd Edition). Missouri: Saunders Elsevier

Board of Agriculture. (1900) "Prices of Livestock: Returned under the Weighing of Cattle Act", Board of Agriculture Journal, 7 (1), 123-127.

Board of Agriculture. (1901) "Prices of Livestock: Returned under the Weighing of Cattle Act", Board of Agriculture Journal, 7 (4), 531-541.

Bonnet, M., Faulconnier, Y., Leroux, C., Jurie, C., Cassar-Malek, I., Bauchart, D., Boulesteix, P., Pethick, D., Hocquette, J.F., Chilliard, Y. (2007) "Glucose-6-phosphate dehydrogenase and leptin are related to marbling differences among Limousin and Angus or Japanese Black x Angus steers", *Journal of Animal Science,* 85 (11), 2882-2894.

Boukha, A., Bonfatti, V., Cecchinato, A., Albera, A., Gallo, L., Carnier, P., Bittante, G. (2011) "Genetic parameters of carcass and meat quality traits of double muscled Piemontese cattle", *Meat Science,* 89 (1), 84-90.

Bowden, J.E. (1962). Beef Breeding, Production and Marketing. London: Land Books Ltd.

Braymont UK (2018). Tree Cattle: Weigh Bar 5000kg/1kg WB5000 [www document]. https://www.braymontscales.co.uk/animal-scales/tree-cattle-weigh-bar-5000kg-1kg-wb5000.html?utm_source=googleShopping&utm_medium=organic&utm_campaign=scales&gclid=CjwKCAjwtIXbBRBhEiwAWV-5nmVBvu8iAuSVLcGKyMSYeas541spKiaYKFyEhwJCXwCGjh_B2iNmYRoCISUQAvD_BwE (accessed 01 August 2018).

Cabassi, P. (1990) "The prediction of lamb carcass composition from objective measurements of fatness taken at slaughter chain speed with the AUS-Meat sheep probe", *Proceedings of the Australian Society of Animal Production,* 18 (no issue no.) 164-168.

Campion, B., Keane, M.G., Kenny, D.A., Berry, D.P. (2009) "Evaluation of estimated genetic merit for carcass weight in beef cattle: Live weights, feed intake, body measurements, skeletal and muscular scores and carcass characteristics", *Livestock Science*, 126 (1-3), 87-99.

Calkins, K.G. (2005) Applied Statistics – Lesson 5: Correlation Coefficients [www document]. http://www.andrews.edu/~calkins/math/edrm611/edrm05.htm (accessed 23 November 2015).

Charles, D.D. (1974) "A method of estimating carcass components in cattle", Research in Veterinary Science, 16 (no issue no.), 89-94

Clarke, A.M., Drennan, M.J., McGee, M., Kenny, D.A., Evans, R.D., Berry, D.P. (2009) "Intake, live-animal scores/measurements and carcass composition and value of late-maturing beef and dairy breeds", Livestock Science, 126 (1-3), 57-68.

Conroy, S.B., Drennan, M.J., Kenny, D.A., McGee, M. (2010) “The relationship of various muscular and skeletal scores and ultrasound measurements in the live animal, and carcass classification scores with carcass composition and value of bulls”, Livestock Science, 127 (1), 11-21.

Coopman, F., Van Zeveren, A., De Smet, S. (2004) “Comparison of slaughter characteristics of “S” and “E” class slaughter bulls of the double-muscled Belgian Blue beef breed using a commercial cutting method”, Vlaams Diergeneeskundig Tijdschrift, 73 (No Issue no), 170-175.

Craigie, C.R., Navajas, E.A., Purchas, R.W., Maltin, C.A., Bünger, L., Hoskin, S.O., Ross, D.W., Morris, S.T., Roehe, R. (2012) “A review of the development and use of video image analysis (VIA) for beef carcass evaluation as an alternative to the current EUROP system and other subjective systems”, Meat Science, 92, (4), 307-318.

Craigie, C.R., Ross, D.W., Maltin, C.A., Purchas, R.W., Bünger, L., Roehe, R., Morris, S.T. (2013) “The relationship between video image analysis (VIA), visual classification, and saleable meat yield of sirloin and fillet cuts of beef carcasses differing in breed and gender”, Livestock Science, 158 (1-3), 169-178.

Cross, H.R., Gilliland, D.A., Durland, P.R., Seideman, S. (1983) “Beef carcass evaluation by use of a video image analysis system”, Journal of Animal Science, 57 (4), 908-917.

Daelemans, W., Goethals, B., Morik, K. (2008) Machine Learning and Knowledge Discovery in Databases. Berlin: Springer-Verlag.

De Boer, H., Dumont, B.L., Pomeroy, R.W., Weniger, J.H. (1974) “Manual on E.A.A.P. reference methods for the assessment of carcass characteristics in cattle”, Livestock Production Science, 1 (2), 151-164.

Department: Agriculture, Environmental Affairs and Rural Development (DAEA). (2005) The Beef Carcass Classification System [www document]. http://agriculture.kzntl.gov.za/portal/AgricPublications/ProductionGuidelines/BeefProduction/TheBeefCarcassClassificationSystem/tabid/111/Default.aspx (accessed 14 November 2011).

Department of Agriculture, Food and the Marine (DAFM). (2013) EU Beef Carcase Classification Scheme [www document]. http://www.agriculture.gov.ie/farmingsectors/beef/eubeefcarcaseclassificationscheme/ (accessed 2 September 2013).

Diaz, M.T., Alvarez, I., De la Fuente, J., Sanudo, C., Campo, M.M., Oliver, M.A., Font i Furnols, M., Montossi, F., San Julian, R., Nute, G.R., Caneque, V. (2005) “Fatty acid composition of meat from typical lamb production systems of Spain, United Kingdom, Germany and Uruguay”, Meat Science, 71 (2), 256-263.

Diez, J., Alberti, P., Ripoli, G., Lahoz, F., Fernandez, I., Olleta, J.L., Panea, B., Sanudo, C., Bahamonde, A., Goyache, F. (2006) “Using machine learning procedures to ascertain the influence of beef carcass profiles on carcass conformation scores”, Meat Science, 73 (1), 109-115.

Dommeyer, C.J., Baum, P., Hanna, R.W., Chapman, K.S. (2004) “Gathering faculty teaching evaluations by in-class and online surveys: their effects on response rates and evaluations”, Assessment and Evaluation in Higher Education, 29 (5), 611-623.

Doohoo, I., Martin, W., Stryhn, H. (2003) Veterinary Epidemiologic Research. Charlottetown, Canada: AVC Inc.

Drennan, M.J., McGee, M., Keane, M.G. (2008) “The value of muscularity and skeletal scores in the live animal and carcass grades as indicators of carcass composition in cattle”, Animal, 5 (no issue no.), 752-760.

Encyclopaedia Britannica. (2010) Livestock Farming [www document]. http://www.britannica.com/topic/livestock-farming (accessed 1 March 2016).

English Beef and Lamb Executive (EBLEX). (2007) Beef Selection and Handling for Better Returns [www document]. http://www.eblex.org.uk/documents/content/news/brp_l_beefbbrp_manual_2_-_beef_selection_and_handling_for_be.pdf (accessed 9 April 2012).

English Beef and Lamb Executive (EBLEX). (2011) A Farmer’s Guide to Selling Finished Beef and Sheep [www document]. http://www.eblex.org.uk/documents/content/publications/p_cp_eblexnfusellersguidefinal010911.pdf (accessed 14 November 2011).

English Beef and Lamb Executive (EBLEX) (2012a) Glossary of Carcase and Meat Quality Terms. [www document] https://beefandlamb.ahdb.org.uk/wp-content/uploads/2013/05/p_cp_glossary_carcase_and_meat_quality_terms031012.pdf

English Beef and Lamb Executive (EBLEX). (2012b) Marketing Prime Beef Cattle for Better Returns [www document]. http://www.eblex.org.uk/documents/content/returns/brp_l_beefbbrp_manual_2-beef_selection310512.pdf (accessed 10 September 2012).

English Beef and Lamb Executive (EBLEX). (2012d) Better Returns Programme [www document]. http://www.eblex.org.uk/returns/ (accessed 10 December 2012).

English Beef and Lamb Executive (EBLEX). (2012e) UK Yearbook 2012 – Cattle [www document]. http://www.eblex.org.uk/documents/content/markets/m_uk_yearbook12_cattle240812.pdf (accessed 5 March 2013).

English Beef and Lamb Executive (EBLEX). (2013a) Beef and Lamb Matters: Communicating with the Industry [www document]. http://beefandlambmatters.blogspot.co.uk/ (accessed 8 April 2013).

English Beef and Lamb Executive (EBLEX). (2013b) Better Returns Programme [www document]. http://www.eblex.org.uk/returns/intro.aspx (accessed 8 April 2013).

English Beef and Lamb Executive (EBLEX). (2013c) UK Yearbook 2013 – Cattle [www document]. http://markets.eblex.org.uk/documents/content/markets/m_uk_yearbook13_cattle110713.pdf (accessed 17 January 2014).

English Beef and Lamb Executive (EBLEX). (2014) UK Yearbook 2014 – Cattle [www document]. http://www.eblex.org.uk/wp/wp-content/uploads/2014/07/UK-Yearbook-2014-Cattle-240714.pdf (accessed 18 January 2016).

Eriksson, S., Nasholm, A., Johansson, K., Philipsson, J. (2003) "Genetic analyses of field-recorded growth and carcass traits for Swedish beef cattle", Livestock Production Science, 84 (1), 53-62.

Essien, A., Adesope, O.M. (2003) "Linear body measurements of N'dama calves at 12 months in a South Western zone of Nigeria", Livestock Research for Rural Development, 15 (4), No page no.

Europa. (2012b) European Union - Commission Regulation (EC) No 1215/2003 of 7 July 2003 [www document]. http://eur-lex.europa.eu/Notice.do?val=285545:cs&lang=en&list=485033:cs,476872:cs,435715:cs,285545:cs,237781:cs,309416:cs,295594:cs,295531:cs,174207:cs,161772:cs,&pos=4&page=1&nbl=10&pgs=10&hwords=&checktexte=checkbox&visu=#texte (accessed 11 December 2012).

Europa. (2012c) European Union – Commission Regulation (EEC) No 344/91 of 13 February 1991 [www document]. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31991R0344:en:NOT (accessed 11 December 2012).

Eurostat – European Commission. 2013. Farm Structure in the United Kingdom [www document] http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Farm_structure_in_the_United_Kingdom#Main_statistical_findings (accessed 2 February 2013).

Everitt, G.C. (1966) "Recent trends in carcase evaluation", Proceedings of the Australian Society of Animal Production. 6 (no issue no.) 268-283.

Farming UK. (2013) Consumers "know little" about farming crisis [www document]. http://www.farminguk.com/news/Consumers-know-little-about-farming-crisis_26041.html (accessed 24 August 2015).

Ferrier, P., Lamb, R. (2007) "Government regulation and quality in the US beef market", Food Policy, 32 (1), 84-97.

Fisher, A. (2007) "Beef carcass classification in the EU: a historical perspective", in C. Lazzaroni, S. Gigli and D. Gabiña (ed.), Evaluation of carcass and meat quality in cattle and sheep. The Netherlands: Wageningen Academic Publishers.

Fisher, A., Heal, J. (2001) Livestock Knowledge Transfer – A DEFRA initiative: Carcass Classification [www document]. http://www.foodassurance.teagasc.ie/NR/rdonlyres/0279BFE9-BCD5-49C5-A365-EF7F6B95FA96/60/CarcaseClassification.pdf (accessed 25 October 2011).

Font-i-Furnols, M., Brun, A., Marti, S., Realini, C.E., Pérez-Juan, M., Gonzalez, J., Devant, M. (2014) "Composition and intramuscular fat estimation of Holstein bull and steer rib sections by using one or more computed tomography cross-sectional images", Livestock Science, 170 (No issue no.), 210-218.

Food and Agriculture Organisation (FAO) (2009) Global agriculture towards 2050 [www document]. http://www.fao.org/fileadmin/templates/wsfs/docs/Issues_papers/HLEF2050_Global_Agriculture.pdf (accessed 05 September 2017)

Franz, N., Piercy, F., Donaldson, J., Richard, R., Westbrook, J. (2010) "How farmers learn: Implications for agricultural educators", Journal of Rural Social Sciences, 25 (1), 37-59.

Fraser, M.D., Davies, D.A., Vale, J.E., Nute, G.R., Hallett, K.G., Richardson, R.I., Wright, I.A. (2009) "Performance and meat quality of native and continental cross steers grazing improved upland pasture or semi-natural rough grazing", Livestock Science, 123 (1), 70-82.

Future Beef (2011) Crossbreeding systems for beef cattle [www document]. https://futurebeef.com.au/knowledge-centre/crossbreeding-systems-for-beef-cattle/ (accessed 20 August 2017).

Genesure Ltd. (2015) ABP VIA Payment [www document]. http://www.genesure.co.uk/payment-for-quality-carcases-1/ (accessed 17 July 2017).

Glasgow Herald (1931) National Mark Beef Scheme: New Committee Appointed [www document]. http://news.google.com/newspapers?nid=2507&dat=19310825&id=kIRQAAAAIBAJ&sjid=KjQNAAAAIBAJ&pg=3894,7720107 (accessed 14 November 2011).

Goe, M.R., Alldredge, J.R., Light, D. (2001) "Use of heart girth to predict body weight of working oxen in the Ethiopian Highlands", Livestock Production Science, 69 (2), 187-195.

Gorter, H., Swinnen, J. (2002) "Chapter 36 Political economy of agricultural policy", Handbook of Agricultural Economics, 2 (no issue no.), 1893-1943.

Green, R.D., Field, T.G., Hammett, T.S., Ripley, B.M., Doyle, S.P. (1999) "Can cow adaptability and carcass acceptability both be achieved". Proceedings of the American Society of Animal Science. Indianapolis. 21-23 July 1999.

Greiner, S.P. (2009) Beef Cattle Breeds and Biological Types [www document]. https://pubs.ext.vt.edu/400/400-803/400-803.html (accessed 06 August 2018).

Hadiuzzaman, M., Bhuiyan, A.K.F.H., Bhuiyan, M.S.A., Habib, M.A. (2010) "Morphometric characteristics of Red Chittagong cattle in a nucleus herd", Bangladesh Journal of Animal Science, 39 (1-2), 44-51.

Halachmi, I., Polak, P., Roberts, D.J., Klopcic, M. (2008) "Cow body shape and automation of condition scoring", Journal of Dairy Science, 91 (11), 4444-4451.

Hansard - Parliamentary Debates. (1930) Beef (National Mark) [www document]. http://hansard.millbanksystems.com/commons/1930/mar/20/beef-national-mark (accessed 15 November 2011).

Hansard – Parliamentary Debates. (1964) Fatstock Guarantee Payment [www document]. http://hansard.millbanksystems.com/commons/1964/feb/03/fatstock-guarantee-payment-mr-t-castle (accessed 5 December 2011).

Hansen, G.R. (2007) The Cattle Site: Crossbreeding systems in beef cattle [www document]. http://www.thecattlesite.com/articles/804/crossbreeding-systems-in-beef-cattle/ (accessed 20 August 2017).

Harris, L.E., Lofgreen, G.P., Kercher, C.J., Raleigh, R.J., Bohman, V.R. (1967) "Techniques of research in range livestock nutrition", Utah State University Agricultural Experiment Station Bulletein (471), 86.

Hayes, B. (2010) Meat Trade News Daily: UK – Remembering 55 years in the Meat Industry by Bill Hayes – Part One [www document] http://www.meattradenewsdaily.co.uk/news/030909/argentina___remembering___years_in_the_meat_industry.aspx (accessed 6 December 2011).

Heinrichs, A.J., Erb, H.N., Rogers, G.W., Cooper, J.B., Jones, C.M. (2007) "Variability in Holstein heifer heart-girth measurements and comparison of prediction equations for live weight", Preventative Veterinary Medicine, 78 (3-4), 333-338.

Hemken, M. (2015) Wyoming Livestock Roundup: Livestock – Campbell looks at cow efficiency, conformation as important traits in herd development [www document]. http://www.wylr.net/livestock/239-cattle/5163-campbell-looks-at-cow-efficiency-conformation-as-important-traits-in-herd-development (accessed 14 March 2015).

Horse.com. (2016) Roma Aluminium Measuring Stick [www document]. http://www.horse.com/item/roma-aluminum-measuring-stick/E006291/ (accessed 5 April 2016).

Hunt, A., Wheeler, B. (2017) BBC News – Brexit: All you need to know about the UK leaving the EU [www document]. http://www.bbc.co.uk/news/uk-politics-32810887 (accessed 20 August 2017).

Hybu Cig Cymru (HCC). (2007) Carcase Classification – Beef [www document]. http://www.hccmpw.org.uk/marketprices/carcaseclassification-beef.aspx (accessed 14 November 2011).

Hybu Cig Cymru (HCC). (2012) HCC Information Bulletin: Technical Article – Beef [www document]. http://www.hccmpw.org.uk/medialibrary/publications/HCC%20Quarterly%20Feb10%20web.pdf (accessed 11 September 2012).

Hybu Cig Cymru (HCC). (2014a) Meat Promotion Wales: Market Prices [www document]. http://hccmpw.org.uk/market_prices/market_prices/individualwelshmarkets?n=Mold&d=2014-01-20 (accessed 03 February 2014).

Hybu Cig Cymru (HCC). (2014b) Market Prices: Carcase Classification – Beef [www document]. http://hccmpw.org.uk/market_prices/industryinformation/carcaseclassification-beef/ (accessed 10 March 2014).

Insausti, K., Goñi, V., Petri, E., Gorraiz, C., Beriain, M.J. (2005) "Effect of weight at slaughter on the volatile compounds of cooked beef from Spanish cattle breeds", Meat Science, 70 (1), 83-90.

Janssens, S., Vandepitte, W. (2004) "Genetic parameters for body measurements and linear type traits in Belgian Bleu du Maine, Suffolk and Texel sheep", Small Ruminant Research, 54 (1-2), 13-24.

Johnson, E.R., Davis, C.B. (1983) "A calliper for determining carcass composition in live cattle and skin-on carcass", Crop and Pasture Science, 34 (6), 825-832.

Johnson, E.R., Davis, C.B. (1991) "The use of physical measurements in live cattle to predict carcass composition", Australian Journal for Experimental Agriculture, 31 (4), 479-483.

Jones, S.D.M., Price, M.A., Berg, R.T. (1978) "A review of carcass density, its measurement and relationship with bovine carcass fatness", Journal of Animal Science, 46 (5), 1151-1158.

Katongole, C.B., Mpairwe, D., Bareeba, F.B., Mukasa-Mugerwa, E., Ebong, C. (2013) "Predicting body weight from heart girth, height at withers and body condition score in *Bos indicus* cattle bulls of Uganda", Livestock Research for Rural Development, 25 (3), No page no.

Kempster, A.J., Cuthbertson, A., Harrington, G. (1982) "The relationship between conformation and the yield and distribution of lean meat in the carcasses of British pigs, cattle and sheep: A review", Meat Science, 6 (1), 37-53.

Kirton, A.H. (1989) "Current methods of on-line carcass evaluation", Journal of Animal Science, 67 (8), 2155-2163.

Knee, B. (2006) State Government Victoria Department of Primary Industries: Assessing Fat Depth [www document]. http://www.depi.vic.gov.au/agriculture-and-food/livestock/beef/handling-and-management/assessing-fat-depth (accessed 5 January 2015).

Kolkman, I., Hoflack, G., Aerts, S., Murray, R.D., Opsomer, G., Lips, D. (2009) "Evaluation of the Rice pelvimeter for measuring pelvic area in double muscled Belgian Blue cows", Livestock Science, 121 (2-3), 259-266.

Kongsro, J., Røe, M., Kvaal, K., Aastveit, A.H., Egeslandal, B. (2009) "Prediction of fat, muscle and value in Norwegian lamb carcasses, using EUROP classification, carcass shape and length measurements, visible light reflectance and computer tomography (CT)", Meat Science, 81 (1), 102-107.

Laerd Statistics. (2015) One-way ANOVA [www document]. https://statistics.laerd.com/statistical-guides/one-way-anova-statistical-guide.php (accessed 21 November 2015).

Lambe, N.R., Ross, D.W., Navajas, E.A., Hyslop, J.J., Prieto, N., Craigie, C., Bünger, L., Simm, G., Roehe, R. (2010) "The prediction of carcass composition and tissue distribution in beef cattle using ultrasound scanning at the start and/or end of the finishing period", Livestock Science, 131 (2-3), 193-202.

Lawrence, T.L.J., Fowler, V.R., Novakofski, J.E. (2012) Growth of Farm Animals (3rd Edition). Oxfordshire: CABI.

Lazzaroni, C., Biagini, D. (2008) “Effect of pre- and post-pubertal castration on Piemontese male cattle. II: Carcass measures and meat yield”, Meat Science, 80 (2), 442-448.

Little, D.A., McLean, R.W. (1981) “Estimation of the body chemical composition of live cattle varying widely in fat content”, Journal of Agricultural Science, 96 (1), 213-220.

Littler, B. (2007) New South Wales Department of Primary Industries: Primefact 662 – Live Beef Cattle Assessment [www document]. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/148355/Live-beef-cattle-assessment.pdf (accessed 4 April 2013).

Livestock Northwest (2013) News: Cattle – Live to Dead Event [www document]. http://livestocknw.co.uk/news/cattle_live_to_dead_event (accessed 8 April 2013).

Long, C.R., Stewart, T.S., Cartwright, T.C., Jenkins, T.G. (1979) “Characterization of cattle of a five breed diallel: I. Measures of size, condition and growth in bulls”, Journal of Animal Science, 49 (2), 418-431.

Lyons, R.M.A. (1965) “Errors in estimating yield and grade of cattle sold on a live weight basis”, Canadian Journal of Agricultural Economics, 13 (2), 27-33.

Maiwashe, A.N., Bradfield, M.J., Theron, H.E., van Wyk, J.B. (2002) “Genetic parameter estimates for body measurements and growth traits in South African Bonsmara cattle”, Livestock Production Science, 75 (3), 293-300.

Maltin, C. (2010) Quality Meat Scotland: Video Image Analysis [www document]. http://www.qmscotland.co.uk/index.php?option=com_content&view=article&id=850Itemid%3D156&Itemid=156 (accessed 19 February 2013).

Martin, P., Bateson, P. (1998) Measuring Behaviour: An Introductory Guide. Cambridge: Cambridge University Press.

McConway K.J., Jones, M.C., Taylor, P.C. (1999) Statistical Modelling using GENSTAT. London: Hodder Headline Group.

McKenzie, S. (2012) BBC News: Meet the UK’s oldest farmers [www document]. https://www.bbc.co.uk/news/magazine-17537153 (accessed 01 August 2018).

McKiernan, B., Sundstrom, B. (2006) Department of Primary Industries: Primefacts – Visual and Manual Assessment of Fatness in Cattle [www document] http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0004/95863/visual-and-manual-assessment-of-fatness-in-cattle.pdf (accessed 4 April 2013).

McKiernan W. A., Hoffman W., Barwick S. A. and Johnston D. J. 1998, 'Feeder Steer Assessments that are Guides to Feedlot and Carcass Performance', *Proceedings of the Beef Products Conference*, NSW Agriculture, Armidale.

Meat and Livestock Commercial Services Limited (MLCSL). (2009) Beef carcase authentication and verification services [www document] http://www.mlcsl.co.uk/pdf/Beef%20Carcase%20Classification%2021Apr.pdf (accessed 10 March 2015).

Mira, J., Ferrández, J.M., Álvarez, J.R., de la Paz, F., Toledo, F.J. (2009) Methods and Models in Artificial and Natural Computation. Berlin: Springer-Verlag.

Munster Cattle Breeding Group (2016) Beef Sires [www document]. http://www.munsterai.ie/siredata.php?id=GPZ&type=beef (accessed 22 March 2016).

Murray, R.D., Cartwright, T.A., Downham, D.Y., Murray, M.A., de Kruif, A. (2002) "Comparison of external and internal pelvic measurements of Belgian Blue cattle from sample herds in Belgium and the United Kingdom", Reproduction in Domestic Animals, 37 (1), 1-7.

National Archives (2011a) Agriculture Act 1967: The Meat and Livestock Commission [www document] http://www.legislation.gov.uk/ukpga/1967/22/part/I/crossheading/the-meat-and-livestock-commission (accessed 12 December 2011).

National Farmers Union (2012) Beef and sheep news – No 31. Stoneleigh Park, Warwickshire.

Nulty, D.D. (2008) "The adequacy of response rates to online and paper surveys: what can be done?" Assessment and Evaluation in Higher Education, 33 (3), 301-314.

National Institute of Social and Economic Research (NISER). (1942) Trade Regulations and the Commercial Policy of Great Britain: Protection of Agriculture and Fisheries – Live Cattle. London: Cambridge University Press.

Newman, P.B. (1984a) "The use of video image analysis for quantitative measurement of visible fat and lean in meat: Part 1 – boneless fresh and cured meats", Meat Science, 10 (2), 87-100.

Newman, P.B. (1984b) "The use of video image analysis for quantitative measurement of fatness in meat: Part 2 – Comparison of VIA, visual assessment and total chemical fat estimation in a commercial environment", Meat Science, 10 (3), 161-166.

New Mexico State University (NMSU) (2002) Managing and feeding beef cows using body condition scores [www document] http://aces.nmsu.edu/pubs/_circulars/CR-575/welcome.html (accessed 5 January 2015).

New South Wales: Department of Primary Industries (2015) [www document]. https://www.dpi.nsw.gov.au/animals-and-livestock/beef-cattle/appraisal/publications/live-cattle-assessment (accessed 01 August 2018).

NexGen Ergonomics Inc. (2015) Baseline® Skin Fold Calipers; Slim Guide Plastic Skinfold Caliper [www document]. http://www.nexgenergo.com/medical/baseline8.html (accessed 5 April 2016).

Nicholson, M.J., Little, D.A. (1988) "Skinfold thickness, condition score and tritiated water space in Boran cattle", International Livestock Centre for Africa Bulletin, 30 (no issue no.), 8-9.

Nicolson, N. (2014) Farmer's Weekly – ABP plan to shift to electronic grading from 18 August [www document]. http://www.fwi.co.uk/livestock/abp-plant-to-shift-to-electronic-grading-from-18-august.htm (accessed June 2017).

Oliván, M., Martínez, A., García, P., Noval, G., Osoro, K. (2001) "Estimation of the carcass composition of yearling bulls of "Asturiana de los Valles" breed from the dissection of a rib joint", Meat Science, 57 (2), 185-190.

Oliver, A., Mendizabal, J.A., Ripoll, G., Alberti, P., Purroy, A. (2010) "Predicting meat yields and commercial meat cuts from carcasses of young bulls of Spanish breeds by the SEUROP method and an image analysis system", Meat Science, 84 (4), 628-633.

Oliver, D.M., Fish, R.D., Winter, M., Hodgson, C.J., Heathwaite, A.L., Chadwick, D.R. (2012) "Valuing local knowledge as a source of expert data: Farmer engagement and the design of decision support systems", Environmental Modelling and Software, 36 (no issue no.), 76-85.

Pabiou, T. Fiske, W.F. Näsholm, A., Cromie, A.R., Drennan, M.J., Keane, M.G., Perry, D.P. (2009) "Genetic parameters for carcass cut weight in Irish beef cattle", Journal of Animal Science, 87 (12), 3865-3876.

Pabiou, T., Fikse, W.F., Cromie, A.R., Keane, M.G., Nasholm, A., Berry, D.P. (2011) "Use of digital images to predict carcass cut yields in cattle", Livestock Science, 137 (1-3), 130-140.

Parish, J.A., Bourg, B.M., Marks, M.L., Simmons, M.B., Smith, T. (2012) "Evaluation of different methods of cattle hip height data collection", The Professional Animal Scientist, 28 (3), 292-299.

Pelenna Patchworks (2016) 300 cm/120 inch Retractable Tape Measure [www document]. http://www.pelennapatchworks.co.uk/quilting-rulers-and-measuring-tools/300cm-120-inch-retractable-tape-measure.html (accessed 5 April 2016).

Peña, F., Santos, R., Juárez, M., Avilés, C., Domenech, V., González, A., Martinez, A., Molina, A. (2014) "The use of ultrasound scanning at different times of the finishing period in lean cattle", Livestock Science, 167 (no issue no.), 381-391.

Phythian, C.J., Hughes, D., Michalopoulou, E., Cripps, P.J., Duncan, J.S. (2012) "Reliability of body condition scoring of sheep for cross-farm assessments", Small Ruminant Research, 104 (1-3), 156-162.

Piedrafita, J., Quintanilla, R., Sañudo, C., Olleta, J-L., Campo, M-M., Panea, B., Renand, G., Turin, F., Jabet, S., Osoro, K., Oliván, M-C., Noval, G., Garcia, P., Garcia, M-D., Oliver, M-A., Gispert, M., Serra, X., Espejo, M., Garcia, S., López, M., Izquierdo, M. (2003) "Carcase quality of 10 beef cattle breeds of the Southwest of Europe in their typical production systems", Livestock Production Science, 82 (1), 1-13.

Pierce, J.C. (1959) "Beef grades and standards; past and present". Proceedings of the Beef for Tomorrow Conference. Washington D.C. 19 – 20 October 1959.

Pitchford, W.S., Deland, M.P., Siebert, B.D., Malau-Aduli, A.E., Bottema, C.D. (2002) "Genetic variation in fatness and fatty acid composition of crossbred cattle", Journal of Animal Science, 80 (11), 2825-2832.

Polkinghorne, R.J., Thompson, J.M. (2010) "Meat standards and grading: A world view", Meat Science, 86 (1), 227-235.

Preston, T.R., Willis, M.B. (1974). Intensive Beef Production (2nd Edition). Oxford: Pergamon Press Ltd.

Prieto, N., Roehe, R., Lavin, P., Batten, G., Andrés, S. (2009) "Application of near infrared spectroscopy to predict meat and meat products quality: A review", Meat Science, 83 (2), 175-186.

Przysucha, T., Grodzki, H., Golebiewski, M., Slosarz, J., Piotrowski, T. (2012) "Analysis of body measurements and pelvis area index of Limousine cows", Animal Science, 51 (No issue no.), 107-112.

Pullar, D. (2001) Meat and Livestock Commission: Selling Beef Cattle and Lambs Dead-Weight [www document]. http://www.docstoc.com/docs/28645097/Selling-beef-cattle-and-lambs-dead-weight (accessed 24 January 2014).

Quality Meat Scotland. (2017) Brexit briefing paper 1: Scottish red meat trade – challenges and opportunities resulting from Brexit [www document]. http://www.qmscotland.co.uk/sites/default/files/qms_briefing_paper_1_-_brexit_-_feb_2017.pdf (accessed 20 August 2017).

Radcliffe, R. (2005) Review of the Agricultural and Horticultural Levy Bodies: Final Report [www document]. http://www.ahdb.org.uk/docs/levy-radcliffe-reviewOct05.pdf (accessed 8 January 2013).

Razook, A.G., Figueiredo, L.A., Nardon, R.F., Gonçalves, J.N.S., Ruggieri, A.C. (2001) "Efeitos de raça e da seleção para peso pós-desmame sobre características de confinamento e de carcaça da 15ª progênie dos rebanhos Zebu e Caracu de Sertãozinho (SP)", Revisita Brasileira de Zootecnia, 30 (1), 115-124.

Renco Corporation (2009) Renco Lean-Meater, Series 12; Ultrasound for Ultra Profits [www document]. http://www.rencocorp.com/lean-meater.htm (accessed 5 April 2016).

Rentfow, G. (2010) How much meat to expect from a carcase [www document]. http://www2.ca.uky.edu/agcomm/pubs/asc/asc179/asc179.pdf (accessed 9 January 2017).

Ribeiro, F.R.B., Thompson, A.J., Aragon, S.N., Hosford, A.D., Hergenreder, J.E., Jennings, M.A., Johnson, B.J. (2014) "Comparison of real-time ultrasound measurements for body composition traits to carcass and camera data in feedlot steers", The Professional Animal Scientist, 30 (6), 597-601.

Ridler, J. (2017) Industry calls for carcase classification review [www document]. http://www.foodmanufacture.co.uk/Regulation/Industry-body-seeks-views-on-carcase-classification (accessed 20 August 2017).

Rius-Vilarrasa, E., Bunger, L., Maltin, C., Matthews, K.R., Roehe, R. (2009) "Evaluation of Video-Image Analysis (VIA) technology to predict meat yield of sheep carcasses on-line under UK abattoir conditions", Meat Science, 82 (1), 94-100.

Robinson, D.L. (2005) "Assessing the accuracy of modelling weight gain of cattle using feed efficiency data", Livestock Production Science, 95 (3), 187-200.

Robinson, D.L., Oddy, V.H. (2004) “Genetic parameters for feed efficiency, fatness, muscle area and feeding behaviour of feedlot finished beef cattle”, 90 (2-3), 255-270.

Roy, J.H.B., Stobo, I.J.F., Ganderton, P., Shotton, S.M. (1973) “The production of beef from pre-ruminant Friesian steers”, Animal Production, 16 (3), 215-222.

Ruatiti Highland Fold. (2012) Frame score chart [www document]. http://www.minihighland.co.nz/html/frame_score.html (accessed 18 February 2015).

Ruechel, J. (2006) Grass Fed Cattle: How to Produce and Market Natural Beef, Massachusetts: Storey Publishing.

Rural Payments Agency (RPA). (2011a) Beef Carcase Classification Scheme: Guidance on Dressing Specifications and Carcase Classification [www document]. http://rpa.defra.gov.uk/rpa/index.nsf/0/da29c0a82f1f9e0c802574cf002f9b26/$FILE/Ver%203%20July%202011.pdf (accessed 14 November 2011).

Rural Payments Agency (RPA). (2011b) Beef Carcase Classification [www document]. http://rpa.defra.gov.uk/rpa/index.nsf/UIMenu/FE9EDE8378F6089F802574CE0049B7CC?Opendocument (accessed 23 January 2012).

Rural Payments Agency (RPA). (2011c) Guidance on the Classification of Beef, Pig and Sheep Carcases, and Reporting Beef, Pigmeat and Sheepmeat Prices [www document]. http://rpa.defra.gov.uk/rpa/index.nsf/0/5cc28a496ae7156f8025770c0034894c/$FILE/20April guidance.pdf (accessed 23 January 2012).

Rural Payments Agency (RPA). (2012a) Beef Carcase Classification [www document]. http://rpa.defra.gov.uk/rpa/index.nsf/UIMenu/FE9EDE8378F6089F802574CE0049B7CC?Opendocument (accessed 13 August 2012).

Sandford, J., Wissocq, Y.J., Durkin, J., Trail, J.C.M. (1982) “Evaluation of productivities of Djallonke sheep and N’dama cattle at the Center de Recherches Zootechniques, Kolda, Senegal”, International Livestock Centre for Africa, 3 (No issue no.), 9-39.

Santos, R., Peña, F., Juárez, M., Aviléz, C., Horcada, A., Molina, A. (2013) “Use of image analysis of cross-sectional cuts to estimate the composition of the 10^{th}-11^{th}-12^{th} rib-cut of European lean beef bulls”, Meat Science, 94 (3), 312-319.

Shapiro, L.S., Swanson, L.V. (1991) “Relationships among rump and rear leg type traits and reproductive performance in Holsteins”, Journal of Dairy Science, 74 (8), 2767-2773.

Schröder, U.J., Staufenbiel, R. (2006) “*Invited Review:* Methods to determine body fat reserves in the dairy cow with special regard to ultrasonographic measurement of backfat thickness”, Journal of Dairy Science, 89 (1), 1-14.

Scott-Browne, H., Cooke, R.J. (2014) Current methods used by English beef farmers in ascertaining prime slaughter condition in beef cattle. *Proceedings of the British Society of Animal Science Nottingham. 29-30 April 2014.*

Shapiro, L.S., Swanson, L.V. (1991) “Relationships among rump and rear leg type traits and reproductive performance in Holsteins”, Journal of Dairy Science, 74 (8), 2767-2773.

Somervaille, A.J., Eveleigh, C.S., Thwaites, C.J. (1986) “Accuracy, repeatability and reproducibility of the anal fold measurement for predicting carcass backfat depth in cattle”, Livestock Production Science, 15 (1), 103-106.

Stareck, M. (1924) Agricultural Tribunal of Investigation: Final Report. London: His Majesty’s Stationary Office.

Statistics Solutions. (2015) Binary Logistic Regressions [www document]. http://www.statisticssolutions.com/logistic-regression-assumptions/ (accessed 7 December 2015).

Steen, R.W.J., Kilpatrick, D.J. (1995) “Effects of plane of nutrition and slaughter weight on the carcass composition of serially slaughtered bulls, steers and heifers of three breed crosses”, Livestock Production Science, 43 (3), 205-213.

Sulieman, A.H., Sayers, A.R., Wilson, R.T. (1990) “Evaluation of Shugar, Dubasi and Watish subecotypes of Sudan desert sheep at El Huda National Sheep Research Station, Gezira Province, Sudan”, International Livestock Centre for Africa, 18 (No Issue no.), 30.

Swali, A., Cheng, Z., Bourne, N., Wathes, D.C. (2008) “Metabolic traits affecting growth rates of pre-pubertal calves and their relationship with subsequent survival”, Domestic Animal Endocrinology, 35 (3), 300-313.

Tatum, D. (2007) Beef Grading [www document]. http://www.beefresearch.org/CMDocs/BeefResearch/Beef%20Grading.pdf (accessed 15 January 2013).

Taylor, D.G., Johnson, E.R., Knott, L.M. (1996) “The accuracy of rump P8 fat thickness in predicting beef carcass fat content in three breed types”, Proceedings of the Australian Society of Animal Production, 21 (no issue no.), 193-195.

Taylor, D.G., Johnson, E.R., Knott, L.M. (1996) “The accuracy of rump P8 fat thickness in predicting beef carcass fat content in three breed types”, Proceedings of the Australian Society of Animal Production, 21 (no issue no.), 193-195.

The Beef Carcase (Classification) Regulations. (1991) SI 2242. London: HMSO.

Tomlin, B. (1961) “The marketing of Irish agricultural output”, Irish Journal of Agricultural Research, 1 (1), 49-66.

Turner, S.P., Navajas, E.A., Hyslop, J.J., Ross, R.W., Richardson, R.I., Prieto, N., Bell, M., Jack, M.C., Roehe, R. (2011) “Associations between response to handling and growth and meat quality in frequently handled Bos Taurus beef cattle”, Journal of Animal Science, 89 (12), 4239-4248.

Tuyttens, F.A.M., de Graaf, S., Heerkens, J.L.T., Jacobs, L., Nalon, E., Ott, S., Stadig, L., Van Laer, E., Ampe, B. (2014) “Observer bias in animal behaviour research: can we believe what we score, if we score what we believe?”, Animal Behaviour, 90 (no issue no.), 273-280.

United Kingdom Accreditation Services. (UKAS). (2012) About UKAS [www document]. http://www.ukas.com/about-accreditation/about-ukas/default.asp (accessed 8 January 2013).

United Nations (2017) Sustainable development goals: World population projected to reach 9.8 billion in 2050, and 11.2 billion in 2100 – says UN [www document]. http://www.un.org/sustainabledevelopment/blog/2017/06/world-population-projected-to-reach-9-8-billion-in-2050-and-11-2-billion-in-2100-says-un/ (accessed 20 August 2017).

University of Sydney. (2017) Tutorial on Logistic Regression Model Building: Model Building Procedure – 5 Basic Steps http://sydney.edu.au/vetscience/biostat/macros/logistic_tut_model.shtml (accessed 3 January 2017).

Venkata Reddy, B., Sivakumar, A.S., Jeong, D.W., Woo, Y-B., Park, S-J., Lee, S-Y., Byun, J-Y., Kim, C-H., Cho, S-H., Hwang, I. (2015) "Beef quality traits of heifer in comparison with steer, bull and cow at various feeding environments", Animal Science Journal, 86 (1), 1-16.

Verbeke, W., Van Wezemael, L., de Barcellos, M.D., Kügler, J.O., Hocquette, J-F., Ueland, O., Grunert, K.G. (2010) "European beef consumers' interest in a beef eating-quality guarantee: Insights from a qualitative study in four EU countries", Appetite, 54 (2), 289-296.

Wall, E., White, I.M.S., Coffey, M.P., Brotherstone, S. (2005) "The relationship between fertility, rump angle, and selected type information in Holstein-Friesian cows", Journal of Dairy Science, 84 (4), 1521-1528.

Wall, P.B., Rouse, G.H., Wilson, D.E., Tait Jr, R.G., Busby, W.D. (2004) "Use of ultrasound to predict body composition changes in steers at 100 and 65 days before slaughter", Journal of Animal Science, 82 (6), 1621-1629.

Wardrop, I.D. (1964) "Beef grading: Production, trade and technical considerations", Meat Industry Bulletin, 7 (7), 7.

Warren, H.E., Scollan, N.D., Nute, G.R., Hughes, S.I., Wood, J.D., Richardson, R.I. (2008) "Effects of breed and a concentrate or grass silage diet on beef quality in cattle of 3 ages. II: Meat stability and flavour", Meat Science, 78 (3), 270-278.

Williams, A.R. (2002) "Ultrasound applications in beef cattle carcass research and management", Journal of Animal Science, 80 (2), 183-188.

Wood, S., Barrett, D.C., Reyher, K.K. (2015) "Comparison of visual assessment and heart girth tape measurement for estimating the weight of cattle in clinical practice", The Veterinary Journal (In press, accepted manuscript).

World Trade Organisation (WTO). (1966) General agreement on tariffs and trade: Group on meat [www document]. http://www.wto.org/gatt_docs/English/SULPDF/91890058.pdf (accessed 5 December 2011).

Wythes, J. (2012) Liveweight Loss and Recovery in Beef Cattle [www document]. http://futurebeef.com.au/topics/markets-and-marketing/liveweight-loss-and-recovery-in-cattle/ (accessed 9 April 2013).

Yeomans, J. (2009) Developments in Carcase Classification of Beef and Lamb – A Farmer's Fund Award [www document].

http://www.nuffieldinternational.org/rep_pdf/1255359445John_Yeoman_Nuffield_Report.pdf (accessed 25 October 2011).

Appendix A – Duffields Beef Finisher Pencils Nutritional Analysis

DUFFIELDS BEEF FINISHER PENCILS (BULK)

Complementary feedingstuff for growing CATTLE, to be fed in conjunction with hay, straw or other forages.

Oil	4.00%	Vitamin A	8000 i.u./kg
Protein	16.00%	Vitamin D3	2500 i.u./kg
Fibre	9.00%	Vitamin E, alpha tocopherol	30 i.u./kg
Ash	9.00%	Copper, copper sulphate	35 mg/kg
Moisture	14.00%	Selenium, sodium selenite	0.30 mg/kg

If fed with additional sources of copper an MFS prescription may be required, consult your veterinary surgeon.

Do not feed to sheep or allow access to effluent from treated animals.

Store in a cool dry place

Ingredients:
40-25% inclusion: Wheatfeed 25-10% inclusion: Wheat, Palm Kernel Exp, Malt Culms, Rape Seed Ext; 10-0% inclusion: Barley, Molasses, Sugar Beet Pulp (unmolassed), Calcium Carbonate, Sodium Chloride, Vegetable Oils, Cattle Supplement.

UFAS Compound Feeds Certificate End Date 30/06/09

W.L. Duffield & Sons Ltd.
Saxlingham Thorpe Mills
Norwich
Norfolk NR15 1TY

Appendix B – Sample Questionnaire

A) Information about Yourself:

1. What is your role in the business?

Owner/occupier ☐
Tennant ☐
Manager/other ☐

2. In which age category do you belong?
(Please circle)

<20 years   20-30 years   31-40 years   41-50 years   51-60 years   >60 years

3. What age did you leave full-time education? ☐ Years

4. Have you any formal agricultural education? ☐ Yes ☐ No

5. If yes, what is the highest level of agricultural education you have achieved?

☐	☐	☐	☐
School only	Further Education *National Certificate/Diploma*	Higher National Diploma	Higher Education *Foundation/Honours Degree*

B) Information about your Farm:

6. Approximately how many finishing cattle are on the premises at any one time? ☐

7. At what age do the cattle go for slaughter?

<12 months	12-18 months	18-24 months	24-32months	32+ months
☐	☐	☐	☐	☐

8. What breed(s) of cattle are owned?

____

9. What type of beef production system is used?

☐	☐	☐	☐
Mainly cereal	Mainly silage-based	Grass/silage-based	Mainly grazed

10. Does your farm follow an organic scheme? ☐ Yes ☐ No

C) Pre-slaughter Methods of Assessment

11. What methods of pre-slaughter assessment are used?
(Tick all that apply)
Visual assessments ☐
Manual handling of points ☐
Weight recording ☐

Other ☐ *Please state* ______________________________

11a. If visual assessments are used, what points on the animal are assessed?

____

11b. If manual handling is used, what points on the animal are assessed?

____

11c. If weight recording is used, at what time of day are cattle weighed?

☐ Morning ☐ Afternoon ☐ It varies

11d. If weight recording is used, what weight are cattle sent to slaughter? ☐ Kgs

12. Is an external assessor ever used to examine cattle prior to slaughter?
Yes ☐ No ☐ Occasionally ☐

13. What carcase classification(s) do you hope to achieve when sending in an animal? Grade: ______________

13a. Approximately what percentage of animals you send to market reach this/these grades?

______________**%**

14. What is the actual classification the majority of your cattle kill out at? Grade: ______________

15. **In your opinion, is it difficult to ensure cattle meet the desired grade?** Yes No

15a. Reasons why it may/may not be difficult to ensure cattle meet the grade:

D) Use of Current Assessment Aids

16. **Are you aware of the EBLEX (English Beef and Lamb Executive) Better Returns Programme?**

☐ Yes ☐ No

17. **If yes, do you ever use the EBLEX (English Beef and Lamb Executive) Better Returns guide to help classify cattle?** ☐ Yes ☐ No

17a. If no, why not?

18. Have you ever attended an EBLEX Live to Dead day? Yes ☐ No ☐

18a. Have you ever attended an abattoir to view carcases? Yes ☐ No ☐

18b. If no, why not?

19. If you have used the EBLEX guide or been on a Live to Dead day, how useful do you find these in pre-slaughter assessment of cattle?

1	2	3	4	5
Unhelpful	Fairly useful	Useful	Very useful	Extremely useful

Covering letter sent with Questionnaire

(date) 2012

Dear Sir/Madam

Linking farm-measurable beef cattle characteristics to carcase classification and specification

Writtle College (in conjunction with the University of Essex) and with the support and backing of the EBLEX (English Beef and Lamb Sector Company) is carrying out a study which aims to link measurable cattle characteristics to carcase classification in the hope of creating a further tool farmers can use to select their cattle prior to slaughter.

An important part of this investigation is to establish current methods of selection and assessment used by beef farmers across the UK. I am writing to invite you, as a beef producer, to voluntarily take part in this investigation by giving information regarding cattle assessment prior to slaughter in connection with carcase classification.

The questionnaire that I am inviting you to complete has been specially designed to take as little time as possible (no more than 5 minutes). I understand that any kind of form-filling is a nuisance and so I apologise for this in advance. However, I hope that you will take the time to complete this short survey in order to help support the UK beef industry in terms of research and development.

Please return the questionnaire in the reply-paid envelope provided. At the end of the investigation we can send you a sheet containing summary information from the survey so you can see the current issues within the beef industry in regards to pre-slaughter assessment. Your answers will be treated in the **strictest confidence.** If you need any further information, please contact me on (01245) 424200 or email me at 98292823@writtle.ac.uk.

Yours faithfully

Hannah Scott-Browne BSc (Hons)

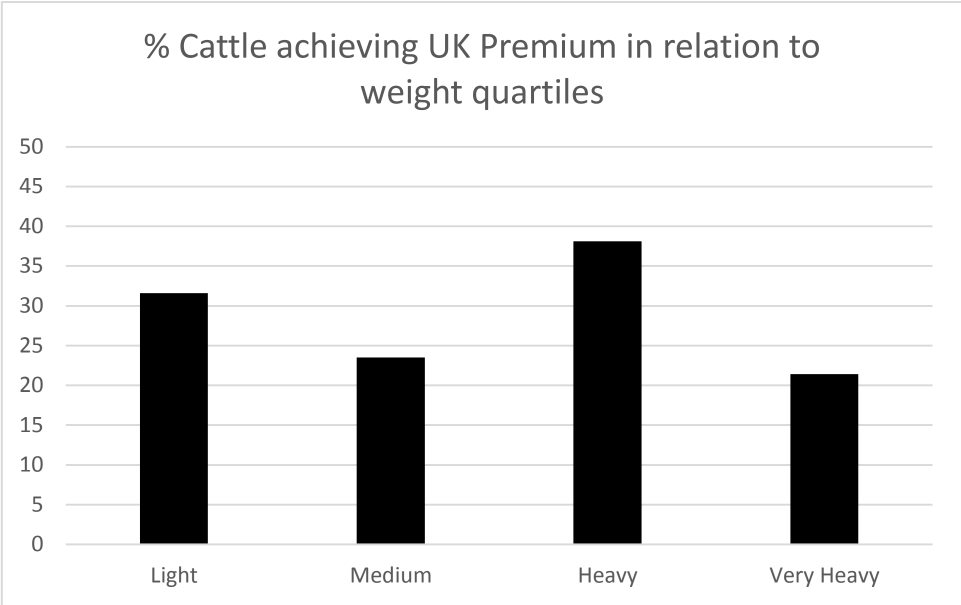
Appendix C - Example of data collection record sheet

Measurement	Notes	Cow 1	Cow 2	Cow 3
Tag number	Individual identification number			
Weight (kg)	Once animal is stationary in crush			
Brisket skinfold thickness (cm)	Skin fold thickness between forelimbs			
Height at withers (cm)	Ground to top of withers			
Width at withers (cm)	From edge to edge of withers			
Length of loin (cm)	From base of tail to centre of withers			
Heart girth (cm)	Measurement around chest, right behind forelimbs			
P8 fat point reading (mm)	Position on rump mid-section, in line with tail base			
10th rib fat point reading (mm)	4 ribs in from tail			
12th rib fat point reading (mm)	2 ribs in from tail			
Anal skinfold thickness (cm)	Requires 2 people - pinch skin at base of tail next to rump			
Height at pelvis (cm)	Ground to top of hook bones			
Width at pelvis (cm)	From edge to edge of pin bones			
Width of rump (cm)	From edge to edge of rump, around the tail			
Length of rump (cm)	From P8 point to flank line			
Round profile	From tail base to hock			
Visual assessment estimate	According to EBLEX guide			

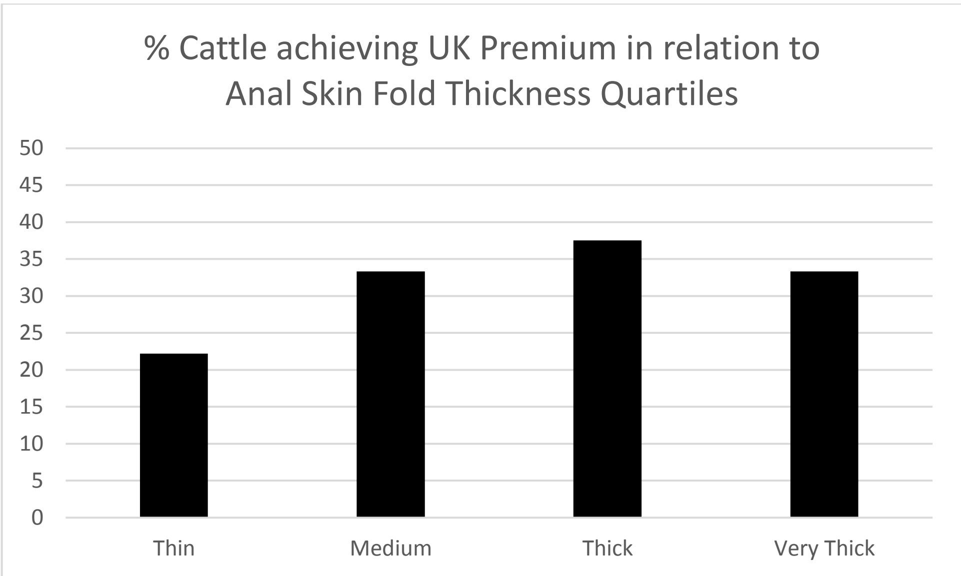
Appendix D - Example of data collection record sheet

Tag Number	Gender	Breed	Pelvis Height	Pelvis Width	10th Rib	12th Rib	P8 Point	Carcase Classification

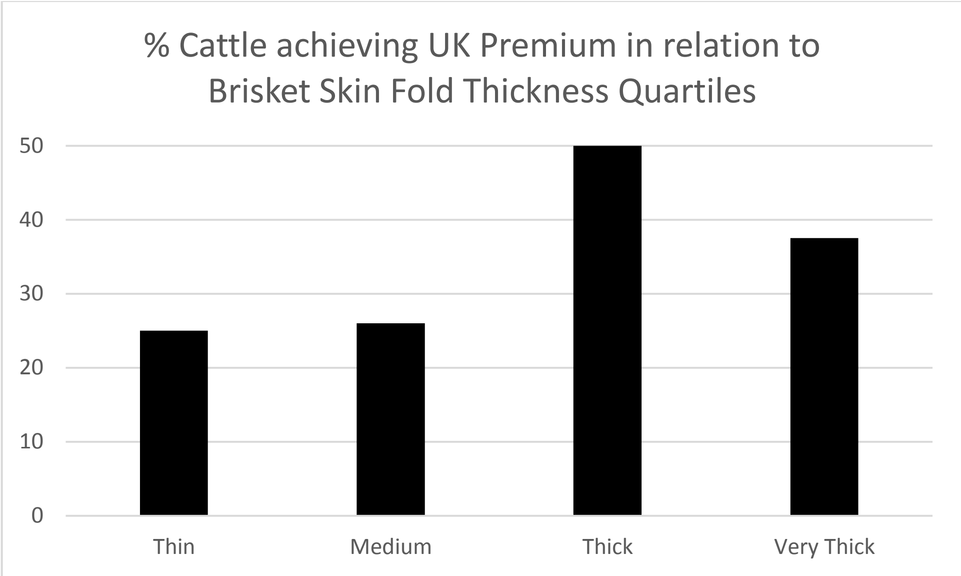
Appendix E - Graphs showing percentage of cattle achieving UK Premium carcase classification according to individual measurement quartiles (Study Three)



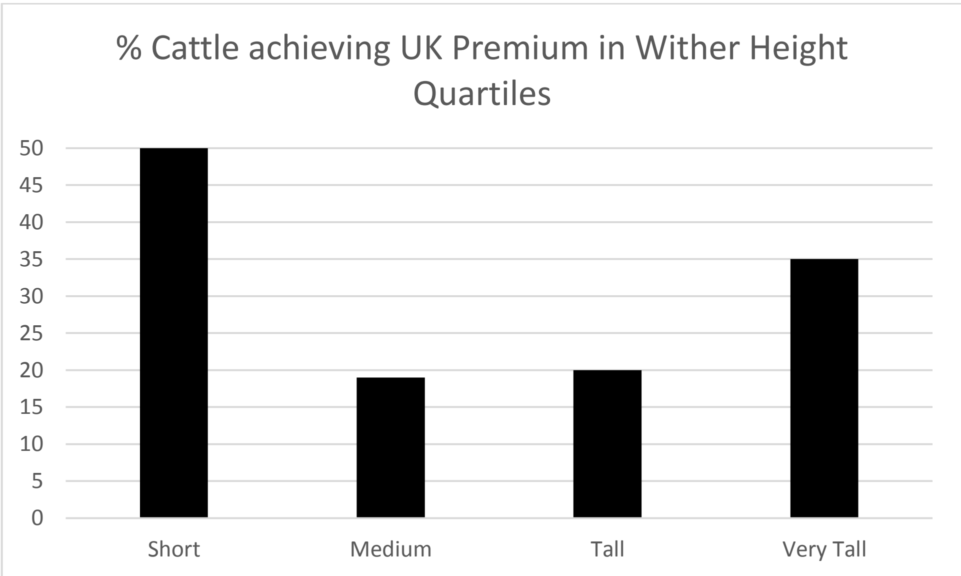
Percentage of cattle achieving UK Premium carcase classification in relation to weight measurement quartiles (Light = 470-545kg; Medium = 546-575kg; Heavy = 576-620kg; Very Heavy = 621-680kg)



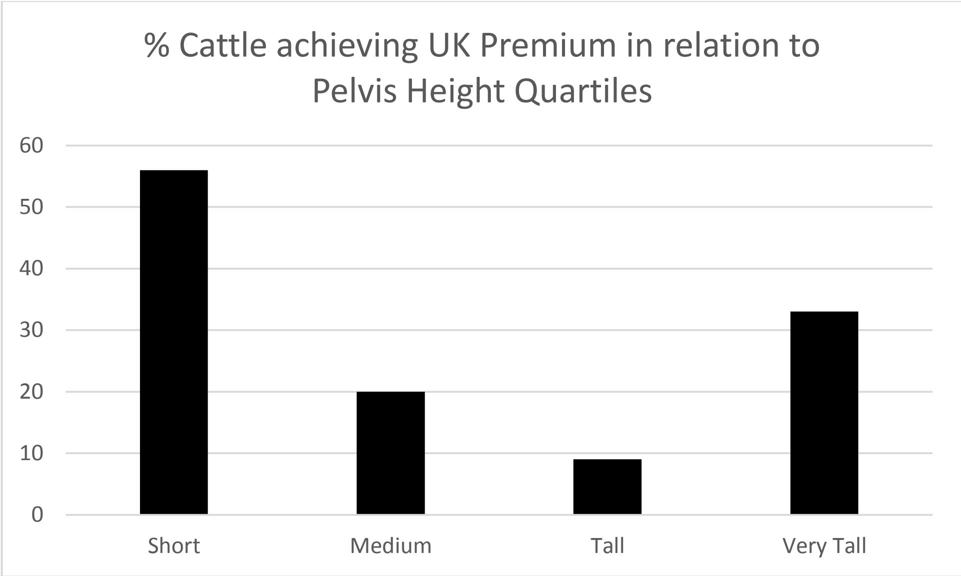
Percentage of cattle achieving UK Premium carcase classification in relation to anal skin fold thickness measurement quartiles (Thin = 0.7-1.2cm; Medium = 1.21-1.6cm; Thick = 1.61-1.9cm; Very Thick = 1.91-3.7cm)



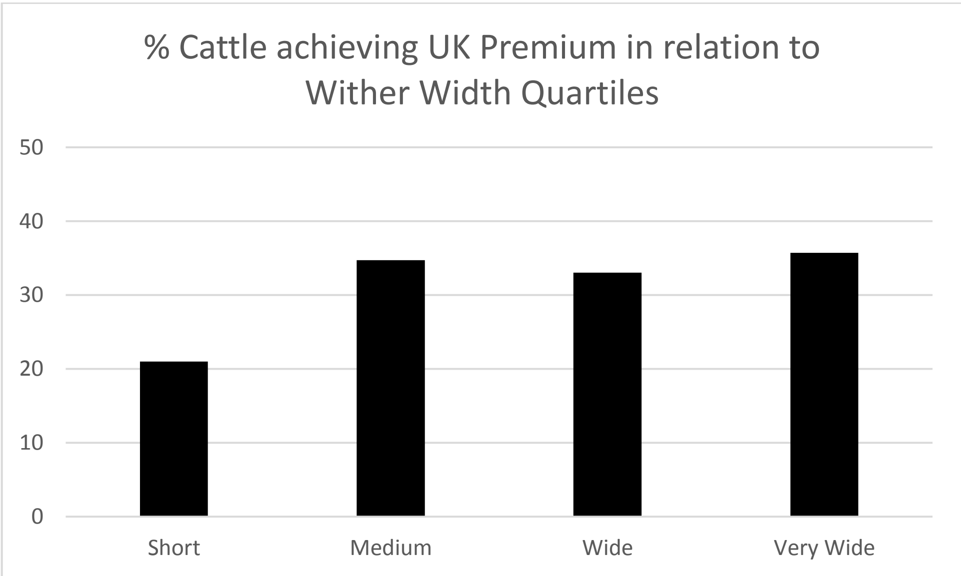
Percentage of cattle achieving UK Premium carcase classification in relation to brisket skin fold thickness measurement quartiles (Thin = 0.7-1.1cm; Medium = 1.11-1.4cm; Thick = 1.41-1.5cm; Very Thick = 1.51-2.4cm)



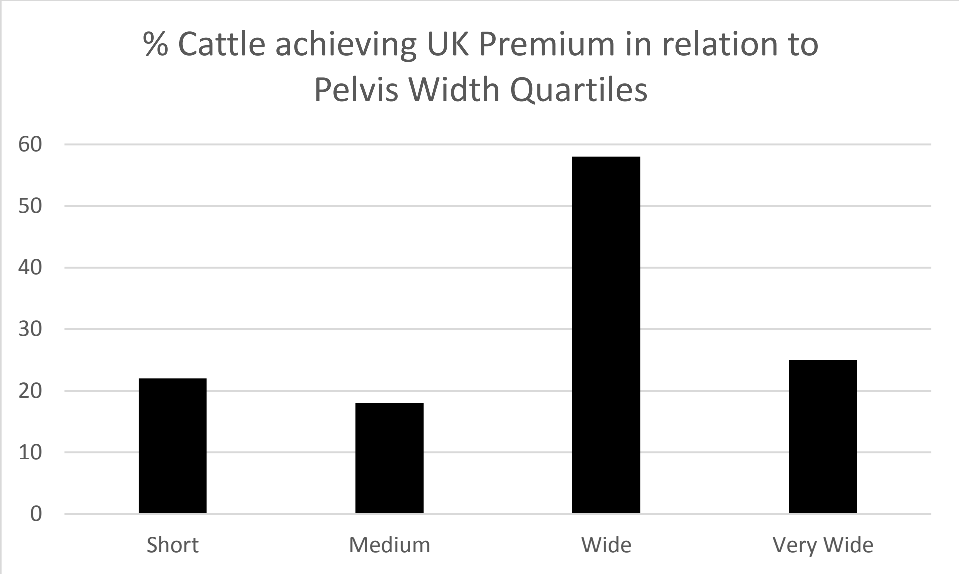
Percentage of cattle achieving UK Premium carcase classification in relation to wither height measurement quartiles (Short = 125-132cm; Medium = 133-136cm; Tall = 137-139cm; Very Tall = 140-147cm)



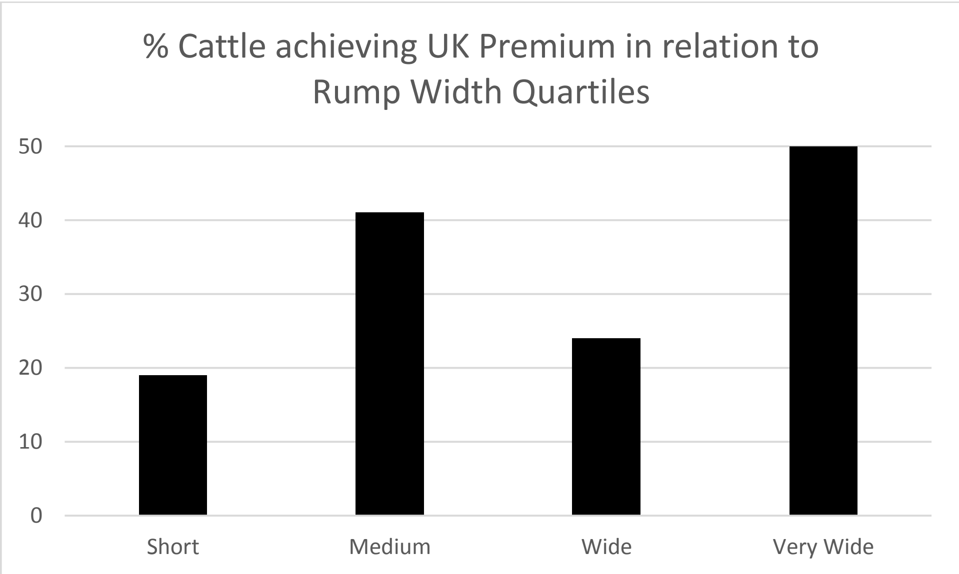
Percentage of cattle achieving UK Premium carcase classification in relation to pelvis height measurement quartiles (Short = 127-136cm; Medium = 137-141cm; Tall = 142-144cm; Very Tall = 145-155cm)



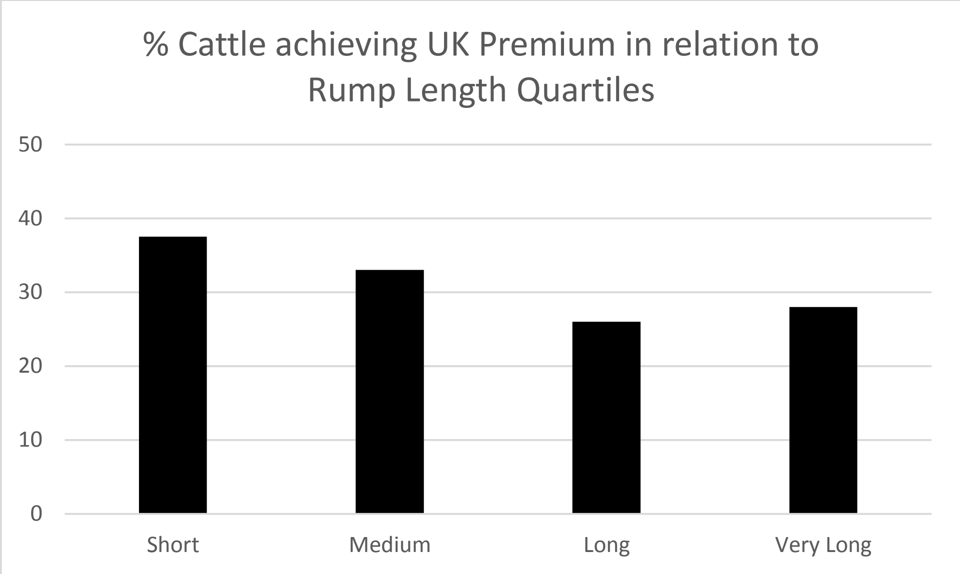
Percentage of cattle achieving UK Premium carcase classification in relation to wither width measurement quartiles (Short = 31-62cm; Medium = 63-70cm; Wide = 71-74cm; Very Wide = 75-85cm)



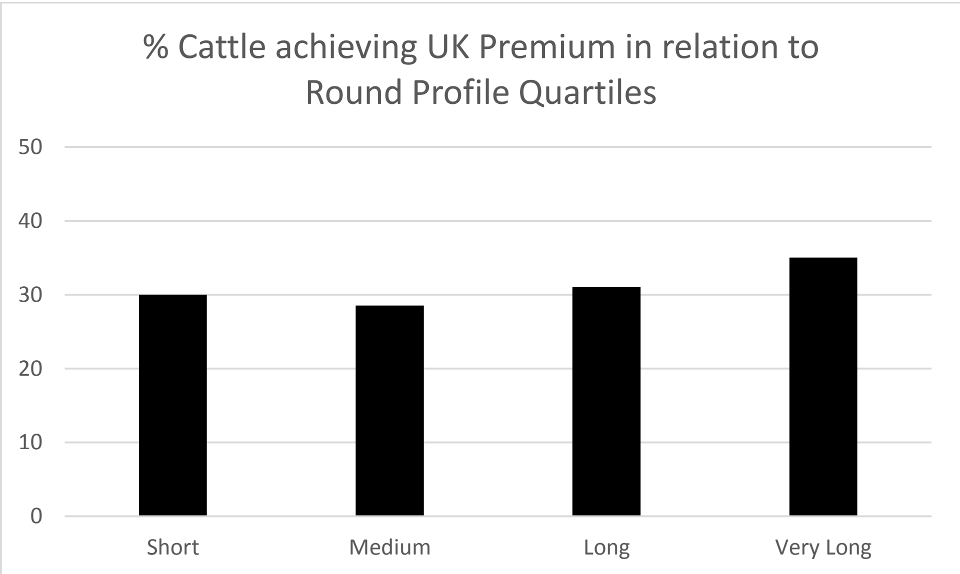
Percentage of cattle achieving UK Premium carcase classification in relation to pelvis width measurement quartiles (Short = 44-69cm; Medium = 70-74cm; Wide = 75-80cm; Very Wide = 81-88cm)



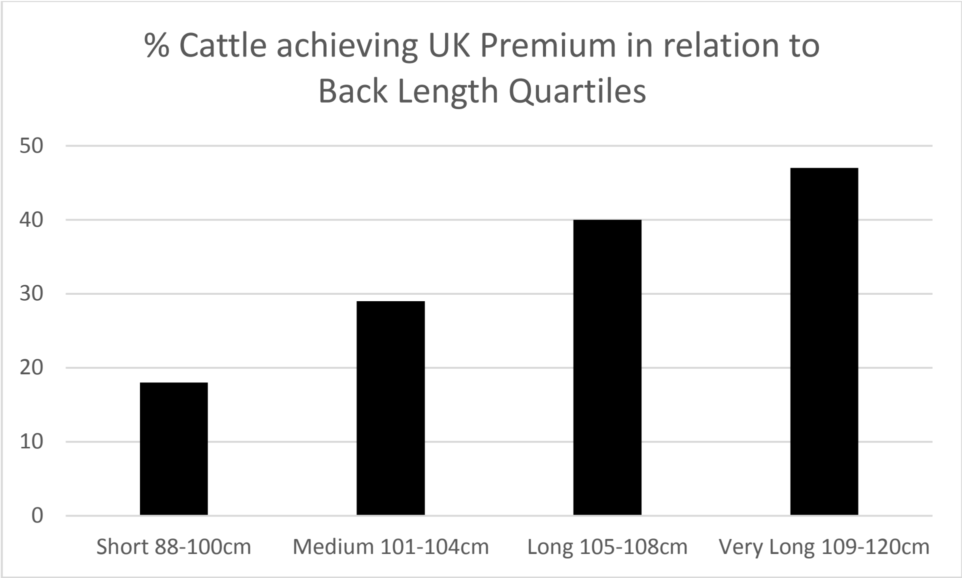
Percentage of cattle achieving UK Premium carcase classification in relation to rump width measurement quartiles (Short = 46-62cm; Medium = 63-70cm; Wide = 71-80cm; Very Wide = 81-95cm)



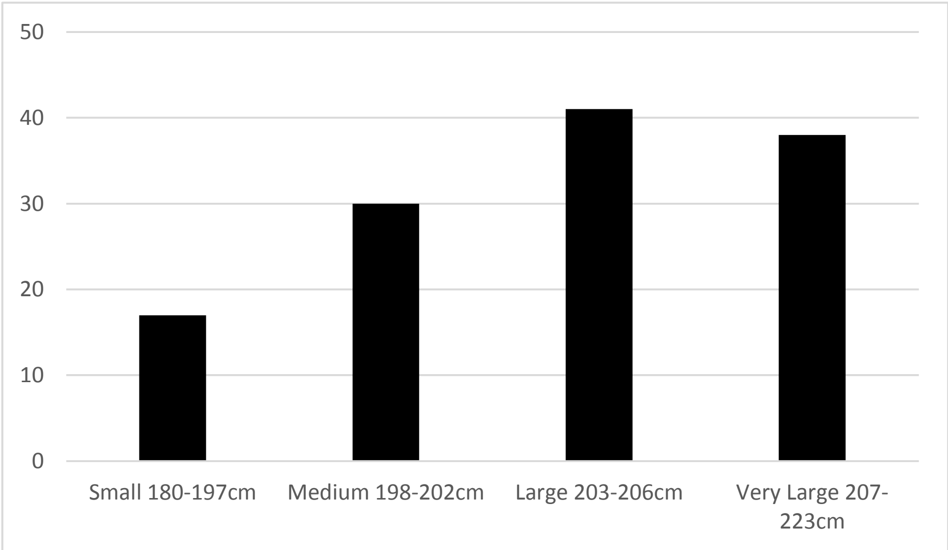
Percentage of cattle achieving UK Premium carcase classification in relation to rump length measurement quartiles (Short = 54-61cm; Medium = 62-63cm; Long = 64-67cm; Very Long = 68-74cm)



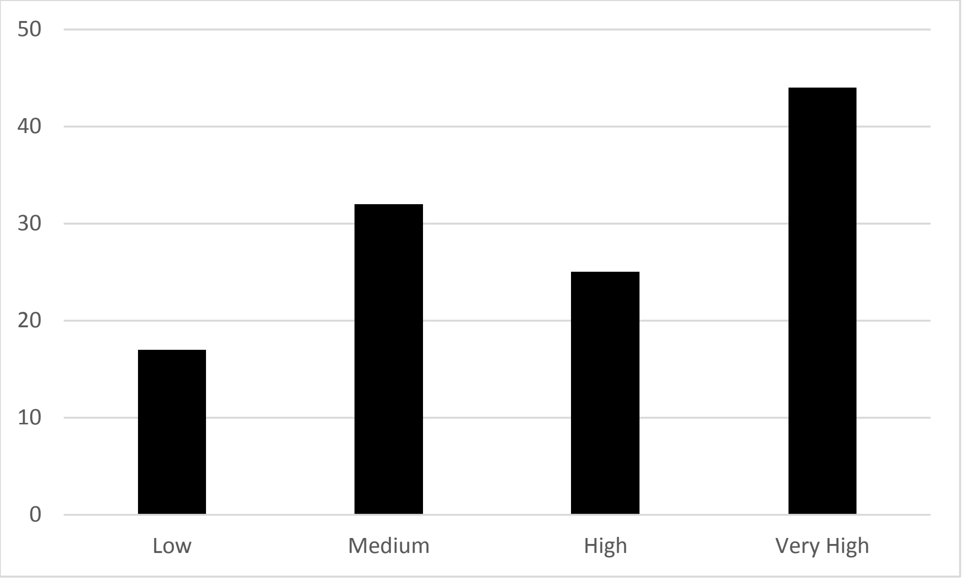
Percentage of cattle achieving UK Premium carcase classification in relation to round profile measurement quartiles (Short = 58-66cm; Medium = 67-70cm; Long = 71-73cm; Very Long = 74-82cm)



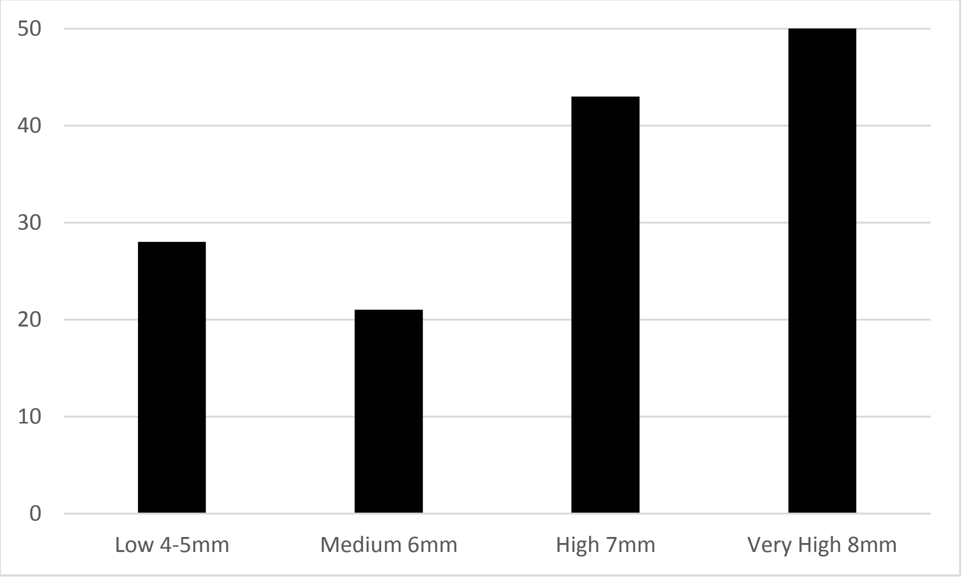
Percentage of cattle achieving UK Premium carcase classification in relation to back length measurement quartiles (Short = 88-100cm; Medium = 101-104cm; Long = 105-108cm; Very Long = 109-120cm)



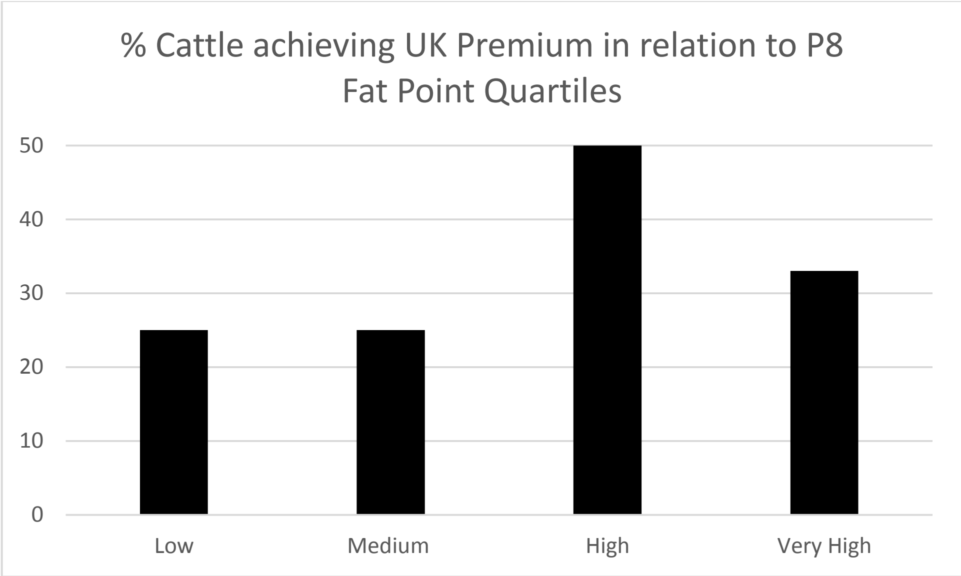
Percentage of cattle achieving UK Premium carcase classification in relation to heart girth measurement quartiles (Short = 180-197cm; Medium = 198-202cm; Long = 203-206cm; Very Long = 207-223cm)



Percentage of cattle achieving UK Premium carcase classification in relation to 10th rib fat point reading measurement quartiles (Low = 4-5mm; Medium = 6mm; High = 7mm; Very High = 8-9mm)



Percentage of cattle achieving UK Premium carcase classification in relation to 12th rib fat point reading measurement quartiles (Low = 4-5mm; Medium = 6mm; High = 7mm; Very High = 8mm)



Percentage of cattle achieving UK Premium carcase classification in relation to P8 fat point reading measurement quartiles (Low = 4-5mm; Medium = 6mm; High = 7mm; Very High = 8-12mm)