THESIS

DECISION SUPPORT SYSTEM FOR COW-CALF PRODUCERS

Submitted by

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ABSTRACT

DECISION SUPPORT SYSTEM FOR COW-CALF PRODUCERS

Sire selection is an important decision directly affecting ranch profitability. The need for decision-support software is increasing with the growing number of EPD available. The objective of this project was to develop web-based tools to evaluate production and economic outcomes from the use of alternative sires. A model which simulates the age structure of a herd to predict performance, revenues and costs while accounting for non-genetic effects such as age of the dam was constructed. Users provide a minimum number of production inputs comprising herd size, pregnancy rate, replacement rate, mature cow size, calf survival, birth and weaning weights. These define an equilibrium age structure and provide realistic production outcomes for the base herd. Genetic variables that simultaneously influence model behavior are limited to those economically relevant traits that are closely aligned to available EPD. These include heifer pregnancy, calving ease direct and maternal, mature cow size, cow maintenance requirements, stayability, birth, weaning and yearling weights as well as weaning weight maternal. These EPD are used to derive a new equilibrium age structure and corresponding performance levels following perturbation of the base situation. The total number of cows is then modified, accounting for any change in feed requirements, to provide annual feed consumption identical to the base herd. Outputs from the model allow a producer to compare current herd production and economic performances to those predicted if alternative sires had been used and the system allowed to re-equilibrate. Primary differences in revenue come from changes to the number and

weight of sale calves. Other contributions to variation in revenue are from values of cull cows, replacement costs and dystocia costs. Primary differences in operation costs come from the number of replacements required and the feed requirements of the predicted herd. Discounting procedures are not included. In contrast to other models, the software provides for sire selection by simulation rather than simply generating economic values for subsequent use.

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Yes it is finally here. No longer am I the longest master's level student in the Department. I'd like to thank to all the graduate students, both past and present, whom have helped me along the way. There are far too many individuals that have significantly influenced on my graduate tenure to name individually but to all breed and genetics students, the select nutrition and meat science students (you know who you are) thanks for all the fun and learning. To my advisors, Dr. Mark Enns and Dr. Dorian Garrick, thank you both for teaching me so much, and Dr. Marshall Frasier for the guidance in this project.

To my family and friends who have continued to encourage and push me to completion. No more will you hear "I'll finish sometime this year". To each and every one of you thanks for always supporting me, keeping me focused on what's important and poking fun at my twelve years of college.

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INTRODUCTION AND OBJECTIVE

Introduction

Sire selection has become a daunting task over the past 10 years with the vast number of EPD available to today's cattle producer. Selection decisions must be based upon not only what is important to customers, but also what will return profit to the ranch to remain in business. As an alternative to traditional methods of selecting sires based upon minimum and maximum EPD, biological modeling allows the use of simulation to find a potential sire based simultaneously upon all of a sire's EPD in combination. Rather than assigning generic economic index values which can be very generalized and not applicable to certain production settings, simulation allows a user to parameterize the system to their unique production situations.

Numerous attempts have been made to model cattle production in an attempt to predict performance differences between different range conditions, different cattle types and differing management styles. Many models have focused on specific areas of the ranch system such as particular environment conditions or particular breed performance. The Texas A&M University Cattle Production Systems Model (TAMU) (Sanders & Cartwright 1979) has been used as a base for much modification. The original TAMU model simulates a cattle herd by splitting it into many age classes and physiological states. Nutritional requirements, fertility potential and death potential are modeled separately for each class. Modifications to the TAMU model include Notter et al. (1979), Kanh and Spedding (1983) and Bourdon and Brinks (1987). Tess et al. (2000) developed a model to simulate cow-calf production focusing on prediction of body composition and resulting performance. Other models which have been developed to predict cow productivity include the Kentucky beef model (Loewer et al., 1981), GRAZEPLAN (Freer, 1997), and a rule based modification of GRAZEPLAN (Romera et al., 2003).

These previous models do not allow for comparison of long term sire genetic effect on current herd productivity. Incorporation of available genetic prediction resources into these models was not included. Since many of these models have been described the advances of EPD in areas such as fertility (heifer pregnancy) and longevity (stayability) have been substantial. Many previous models require the parameterization of available feed in the form of dry matter available, crude protein or other nutritional units of measure which are typically difficult to quantify.

Objective

The objective of the project was to produce a decision support system for cow-calf beef cattle producers. The overreaching goal was a system which was user friendly and simplistic while remaining accurate and robust. Parameterization of production was sub-divided into four user entered sections; economics, genetics, management, and production categories. The system was paired with database of sire summaries to allow filtering and selection of multiple sires to simulate mating to. Simulation of beef cattle herd age structure, growth potential, nutritional requirements, calving ease and financial factors were identified as key parts of the model. Genetic predictions of potential performance are included in this simulation for available EPD and have a substantial effect on the outcome of sire selection. The user is returned an economic figure accounting for a bull’s entire genetic merit.

Chapter II

REVIEW OF LITERATURE

Selection

The earliest fossil evidence of human's domestication of animals occurred approximately 14,000 years ago (Davis and Valla, 1978; Leonard et al., 2002). Since that time artificial selection has been imposed upon domesticated animal for traits and attributes beneficial to man. Through time, selection pressure has progressed from structural traits and visual appraisal to production traits and underlying genetic merit. Early on it was recognized that selection pressure on males will yield quicker progress due to the greater number of offspring a male can make in a single year. The most common selection tool used today to identify the very best males comes in the form of expected progeny difference (EPD).

The first large scale genetic evaluation to provide producers EPD was published in the early 1970's (American Simmental Association, 1971). Applying the methods of Henderson (1966) national cattle evaluation became possible and revolutionized the way superior animals were identified. Over the next forty years advancements have been made in the number of traits evaluated, the number of animals evaluated and more advanced ways to use EPD in multiple trait selection. Today's cattle breeder has a variety of tools available to assist them in choosing which sires to use in their herd. Many breed associations have made sire summaries available online that include the ability to sort and filter based upon selection criteria.

However this amount of information has made selection a daunting task. Misuse in how to correctly apply EPD, the meaning of individual EPD and accounting for relationships among EPD are all obstacles producers face when making selection decisions. Most producers are left with choosing a few EPD to focus on and ignoring the rest. This leads to not using all the information available nor taking full advantage of technology. For a selection decision to have the greatest intended impact two important criteria need to be considered, which traits to select for and how to combine them into a manageable form. Important traits will depend on a producer's previous selection decisions and marketing strategies. Methods for combining multiple EPD into single a value to capture all the information in a more manageable form has been studied extensively using two primary approaches, selection indices and computer simulation/decision support models.

Selection Criteria

Selecting animals to become the foundation for future generations is a decision which carries long term impact. Deciding which animals are the best may be different depending upon the goals or objectives of each individual producer. A guide to navigate the steps required to reach an answer to what is best is illustrated in figure 2.1 (Harris et al., 1984, Garrick and Golden, 2009). The first step in the process is to identify a goal. A broad definition of this goal may be to remain in business by being profitable. Although this is a very general goal, unless a producer is breeding cattle as a hobby, it is a very important one and thus the focus of this project. If profitability is the goal then producing a product that will return the greatest amount may be the objective. Exercises such as this are necessary to avoid being lost to information overload or chasing trends that won't remain viable long term.

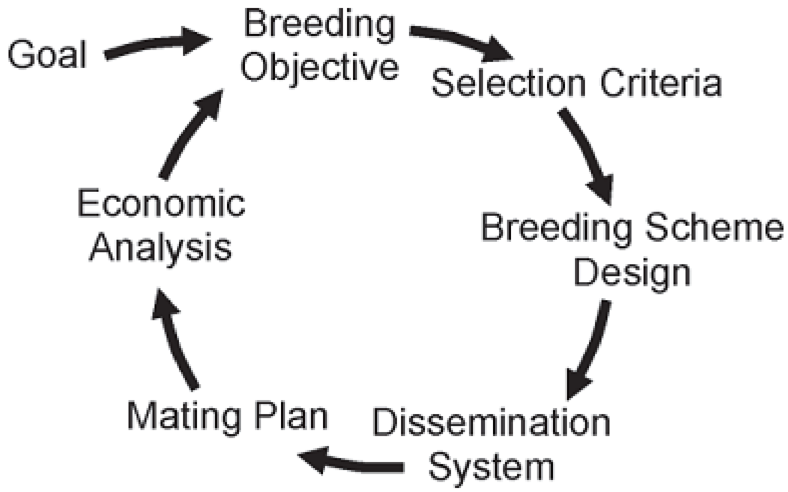

Figure 2.1. Steps involved in system approach of selection goals and advancement (Garrick and Golden, 2009, adapted from Harris et al., 1984)

After the goal had been identified, the remainder of the process revolves around what traits are biologically and economically relative to the goal. Assuming profitability is the goal then producing an animal that will net the greatest return within a given production scenario can be considered best. Eleven years ago Golden et al. (2000) formally introduced the concept of economically relevant traits (ERT) to the industry defined as:

> "Economically relevant traits are the traits that directly affect profitability by being associated with a specific cost of production or an income stream. Indicator traits add information to the prediction of economically relevant trait."

In that paper, a distinction was made between two categories of EPD. These two categories were ERT and indicators of ERT. To be an ERT the trait must have a measurable/quantifiable value on financials of production. An indicator trait is one that may be related to an ERT but by itself does not directly affect the revenue stream of enterprise. The list of Golden's proposed traits is presented in Table 2.1. Priority of these ERT may be different for each cow-calf enterprise, based upon their particular marketing strategy, genetic strengths of their herd, production environment or economic structure.

Table 2.1. Proposed economically relevant traits and their indicators important in cow-calf production (adapted from Golden et al., 2000)

Economically relevant trait	Indicator traits[1]
Sale Weight Weaning Direct Weaning Maternal (Milk) 600 d Direct Carcass Weight Direct Salvage Cow Weight	Birth weight 205 d Weight 365 d Weight Carcass weight Fat Thickness Cull Cow Weight
Probability of Calving Ease	Calving Ease Score Birth weight Gestation Length Pelvic size
Cow Maintenance Feed Requirements	Mature Cow Weight Body Condition Score Milk production Gut Weight
Stayability or Length of Productive Life	Calving Records Days to Calving Calving Interval Milk Production
Heifer Pregnancy Rate	Pregnancy Observations Scrotal Circumference Age of Puberty

[1] Indicators means traits which are measured to provide information to produce the economically relevant trait EPD. This list contains just the obvious indicators. It is likely that different situations will be able to use other indicators

[2] Sale weight is a category of EPDs. Different breeders will have different times at which they believe the future sales will occur for calves resulting from current breeding decisions. Each situation will require the breeder to use only one of the sale weight EPDs.

Selection index

Selection index, a weighted combination of economic values and selection criteria for multiple trait selection, was first described by Hazel and Lush (1942). The purpose of developing selection indexes was to maximize economic response from multiple-trait selection (Hazel, 1943). Advancing from single trait selection, selection index offers a method for combining multiple pieces of information into a single value to assess genetic and economic merit of an individual simultaneously. This method of combining all traits of the breeding objective into a single value is a more efficient pathway to attain the breeding goal than selecting for multiple traits independently. The formula of selection index presented by (Hazel, 1943) is:

$$I = b_1X_1 + b_2X_2 + \cdots + b_nX_n$$

Where ***I*** is the aggregate index value, b are the relative economic values for each trait in the selection criteria and X represents the performance of individual or groups of animals expressed as phenotypes or breeding values. As selection tools evolved the availably and quantity of traits with EPD increased methods for utilizing selection indices has as well. Substitutions of EPD for phenotypes and economic values for weights have become a common form of Hazel's original formula. EPD replacement of phenotypes in the index also introduces ways to account for other effects such as inbreeding and contemporary group effects. However, as noted by many authors on the subject EPD may not be available for all ERTs so the necessity to estimate correlations and co-variances among these and indicators traits is still necessary (MacNeil et al., 1997; Hazel et al., 1994).

Performance information only makes up half of the selection index equation, economic values still being required. Derivation of economic values has traditionally been accomplished from one of two methods, either though economic simulation (Cartwright, 1970) or the partial derivative of a profit equation (Harris, 1970). These profit equations are typically complex in nature, summarizing all economic facets of a beef production system. These economic values are generally only applicable under the scenario used in the derivation and can be subject to difference in cost/revenue assumptions as well as genetic level of herds. MacNeil et al. (1997) suggested that given the lengthy generation interval of beef cattle, when deriving these economic values, average prices from a 10 to 15 year period should be used.

The question arises of which traits should be included in the index? There are several approaches to answer this. Ideally the index would include all economically relevant traits. (Gjedrem, 1972). However this is seldom possible because the relationships between many of these traits or the economic weights are difficult to derive and apply due to operation specific dependencies. The proposed flow diagram of Harris et al. (1994) (figure 2.1) leads to trait selection once a goal, objective and selection criteria have been defined. For producers who have not gone through the planning stage, the list is not nearly as explicit. Sivanadian and Smith (1997) showed a diminishing return to adding additional traits if they are highly correlated to other traits or low in heritability.

Upton et al. (1988) proposed the use of customizable indexes for individual producers. However this is only possible for the largest of producers. The cost associated with the research required to identify which traits to include in the selection as well as the derivation of economic weights for these traits would be too great.

Index selection has been shown successful by MacNeil (2003) who investigated the long term effect of selecting on an index originally proposed by Dickerson et al. (1974). The index consisted of 2 traits, birth weight (BWT) and yearling weight (YWT) as illustrated in the formula:

$$I = YWT - 3.2 * BWT$$

Using the index in a research population of composite cattle increased yearling and birth weight 23.2 kg and 1.35 kg respectively after three generations of selection. Correlated responses in other weight traits were also observed. Increases in 200d weight and mature weight were reported to be 10.3kg and 22.2kg respectively. Only minor responses in maternal effects were observed. These results illustrate a potential downfall in selection indexes, genetic antagonisms. Using an index which included yearling weight, an economically relevant trait when selling animals at a year of age, selection successfully increased yearling weight. However if females born under this selection strategy were kept until maturity there would be a potential increase in feed required to maintain these animals due to correlated increases in mature size. While this index was successful in its design, including mature weight in the index as well would have addressed the long term effects on female requirements due to correlated increases in mature size.

Using a more complex economic selection index, Enns and Nicoll (2008) reported the results of selection for economic return using the traits harvest weight, dressing percentage, net fertility (measured in number of calves weaned) and cow body weight over 17 years. The index originally devised by Morris et al. (1978) and further described by Nicoll et al. (1979) was

$$I = 0.53 * HW * D_P * (4.8 * F - 1) + 0.06 * M * D_M$$

Where I was net income per cow lifetime, HW represented harvest weight, D_P and D_M was dressing percentage for progeny and cull cows respectively, M was body weight at disposal and F was calves weaned per cow exposed. Over the 17 years of selection response to the index traits was 28.9 kg, 2.2 kg, -0.595% and 0.021 calves for the traits harvest weight, mature body weight, dressing percentage and calves weaned per cow exposed respectively. Economically, average returns of an additional $22.87 per year per cow were realized over the life of this study.

More recently, many breed associations have begun to include generic selection index values in sire summaries. These values, often termed ‘dollar value indexes’, have proliferated to include maternal, carcass, and growth traits. However details concerning the traits included in these indexes, weighting factors of individual traits and the assumed cost and pricing structure to derive the dollar amounts has not been transparent or detailed (Garrick and Golden, 2009). In order for rankings of ‘dollar value indexes’ to remain constant, selection objectives, production environment and economic situation must be the same for each user of a generalized selection index. Using such an index to make selection decisions can be risky. If the traits included in these ‘black box’ indexes are not necessary to achieve the goal or the economic values do not reflect those of the user selection pressure may not be at an optimum (Garrick, 2005). Breed association sire summaries including such index values include; American Angus Association (weaned calf, cow energy, feedlot value, grid value, beef value), American Hereford Association (Baldy maternal index, calving easy index, Brahman influence index, Certified Hereford index), American Gelbvieh Association (carcass value and feedlot merit), North American Limousin (terminal index).

Computer aided beef cattle selection

Using computer modeling to predict future outcomes can be a useful tool to account for production, management and economic changes over long periods of time. Computer simulation has been shown to be advantageous to selection indices because of the ability to parameterize individual management and environmental details (Garrick, 2005). In general there are two types of computer models, simulation models and decision support system (DSS) models. Simulation models tend to be more scientifically targeted, some requiring a vast number of parameters. These complex models attempt to completely describe all variables of a production scenario. Though based on simulation, DSS models may utilize databases to simplify inputs required by the simulation models. Variables that would remain static within an operation over time, such as environment, can be assumed constant as both the baseline and potential simulation would be subject to identical conditions. This allows DSS to focusing primarily on summary of simulation results into fewer outputs. Examples of each type will be reviewed separately.

Beef Cattle Simulation Models

There have been many models published with the ability to predict or simulate beef production. As computer power was developed and further optimized the number of beef cattle production models increased. In a review of simulating beef production biological systems Joandet and Cartwright (1975) noted development of simulation models requires:

> …the application of knowledge from different disciplines; developing a beef production model may involve nutrition, reproduction, genetics, forage production, management, operational research, economics, mathematics and possibly other fields.

Through the 1970’s a variety of models were described in literature (Long et al., 1975, Wilton et al., 1974, Sanders and Cartwright, 1979).These early models simulated production in a variety of ways including input-output based, nutrient requirement based, production region specific, drought versus normal, different cattle types and differing management styles. Many of these first models served as the basis for future models, these include but are not limited to the Texas A&M beef model (Sanders & Cartwright 1979), Colorado Beef Cow Production Model (Shafer, 2003), and a host of smaller or partial models. Application of many simulation models has been restricted to the research arena because of the complex nature and parameterization of many of these models.

Perhaps the most often cited and modified simulation model has been the Texas A&M University Cattle Production Systems Model (TAMU) (Tess and Kolstad, 2000a). It has been modified and validated to predict production in a variety of environments under varying herd sizes and management practices. First described by Sanders and Cartwright in 1979 (Sanders and Cartwright 1979a,b), the deterministic model simulates levels of performance from specified feed resources and cattle production potentials. Using a monthly time step the model is able to simulate production across years. The model is driven by three primary routines, growth, fertility and death. Simulated animals are classified into groups by age in years, lactation status (monthly basis) and pregnancy status. Calves are classified by age in months and age of dam. All replacements are assumed to be generated within system. Herd dynamics are characterized by simulating growth of individual classes of animals, fertility of females and the loss of animals to either death or sale. Growth of animals is simulated by allocating available feed resources to first meet requirements for survival and physiological status (gestation, lactation, etc.). Requirements for lean gain are met next and any surplus available energy goes into fat deposition. In the event of nutritional deficiencies, production of milk and lean growth is reduced. Fertility is simulated separately for heifers versus cows. Heifers are evaluated for degree of maturity, body condition, weight gain, genetic reproduction potential and this information is then used to determine breeding success. Cows are evaluated for body condition, weight gain, lactational status, postpartum interval and genetic reproduction potential. Death losses are simulated as functions of the time of year, age, body condition and physiological status of animal groups.

In developing the prediction equations for the TAMU model all equations had to be biologically interpretable (Sanders and Cartwright, 1979b). Differing from previous models the TAMU model does not rely on detailed input data but rather uses given feed resources and production potentials to predict performance. To parameterize the growth prediction model inputs for digestibility, crude protein and availability of forage are required. Inputs for genetic potential of animals include size, maturing rate, milk production and reproductive performance. Based on the modeled relationships between forage quality, amounts, and production potentials, a series of constant parameters complete the model. Differing environments and managements practices are assumed to be accounted for in the forage inputs and production potentials respectively.

Previous to the published description of the TAMU model it had been used in several different simulation studies representing different production environments (Davis et al., 1976; Sanders, 1977; Cartwright, 1977; Ordonez et al., 1977; Nelsen et al., 1978; Ordonez, 1978). Environments for these applications ranged from Botswana, Venezuela, Guyana, to central Texas. The authors recommend that due to the complex nature of the model it is best served not as a producer tool but as a research and teaching tool to transmit knowledge back to producers (Sanders and Cartwright, 1979a)

Subsequent modification of the TAMU model was done by Notter et al. (1979a) to extend the nutritional equations for a more “complete” modeling of nutrient utilization. These changes included varying digestibility of forage, imposing maximum daily milk intake of suckling calves, introducing a dynamic gut fill parameter, changing limits on dry matter as well as incorporating heterosis values for growth and milk production. The modifications of Notter et al. (1979a) were designed to investigate the effects of level of milk production on beef production efficiency in a Midwestern cow-calf-feedlot system. The study simulated three levels of milk production and differing pregnancy, calf survival, weaning and replacements rates. Finally various feed management strategies were compared for economic impacts. Through simulation it was shown that increasing milk production along with weaning rate/calf survival increased economic performance of the system. The exact optimum of milk production was shown to vary based upon feed prices. In a separate study using the same model, Notter et al. (1979b) simulated different mature body size for biological and economic efficiency. Body size was found to have little biological effect, but management and pricing changes were found to effect optimal body size as evaluated through profitability.

In another modification of the TAMU model, Kahn and Spedding (1983) outlined modifications designed for smaller herd sizes of developing countries. Primary changes included; calculating individual animal performance instead of herd-class; addition of stochastic events including conception, mortality, and calf sex; variable time steps of 1 to 30d; additional management options of feed supplementation, drought animals and culling in response to external events; time-scalable output options up to a 10yr in the future; and updated biological functions from recent literature. It was concluded that individual animal simulation benefited from single day time intervals, when herd sizes were small. Over multiple years a monthly time interval gave equivalent values of calf live weight sold. Subsequent literature of validation of the models output and performance were also published by Kahn and Spedding (1984) and Kahn and Lehrer (1984).

Building on the modified TAMU model outlined by Notter (1977, 1979), Bourdon and Brinks (1987a, b, c) added additional capabilities and changed inputs to represent northern plains range cattle environment. These modifications were the beginning of what would become known as the Colorado Beef Cattle Production Model. A more detailed explanation of changes made to Notter's version of the TAMU model is detailed by Bourdon (Dissertation, 1983). In brief, modifications included:

- A Dynamic growth curve which used three points in time to simulate growth potential: birth, yearling and mature weight;
- Heterosis values for birth weight as well as growth from birth to maturity and milk production;
- Different calving difficulty equations for heifers versus mixed age cows;
- Cold weather effects on energy requirements;
- Preferential eating habits;
- Body composition of mature cows;
- Herd size scaling to fixed land resources;
- Variable fertility parameters; and
- A separate economic model of biological outputs

In the three paper series Bourdon and Brinks (1987a, b, c) simulated the production of growth, milk production, and fertility separately in an effort to assess differences between culling strategies and management decisions. Some of these varying management factors included selling calves at weaning versus yearling, placing cull cow into a feedlot versus going directly to harvest. Their conclusions from the simulations were that the interactions among traits give different optimums under different management and economic considerations. Simulations showed larger, faster growing cattle, high milking cows and calves with lighter birth weights produced the greatest economic return when feed was at standard levels. Under scenarios when increased feed costs were considered, at the ranch or feedlot level, the optimal size of cattle was different. Medium and small sized cows with lower milk production were efficient when feed costs were high.

Simulating varying fertility factors showed the highest pregnancy rate was the most economically beneficial. The most fertile females tended to be the least feed efficient in terms of feed inputs required versus weight of saleable product produced. Although the model was unable to dynamically account for stressors (restricted feed) one could presume that these animals may not perform at the same level under less than optimal conditions in real-world settings. Herd wide profitability was dependent on fertility but also dependent on the price of cull heifers and cows. Sale of open stock only changed the source of income, from the calf crop to salvage values, not the overall value of the system.

In 1987 a model based on the original TAMU model (Sanders and Cartwright, 1979) and many of the ensuing modifications (Notter, 1977, Bourdon, 1983) became known as the Colorado Beef Cattle Production Model (CBCPM) (Shafer et al., 2005). The CBCPM extended previous versions with the addition of plant and economic simulation modules. Evaluating pre-existing models for each of the enhancements, the Agriculture Research Services Simulation of Production and Utilization of Rangelands (SPUR) model (White and Skiles, 1987; Hanson et al., 1992, Baker et al., 1992) was selected as the most robust plant model available and modified to interface with the CBCPM. The General Firm Level Policy Simulation Model (FLIPSIM) (Richardson and Nixon, 1986) was chosen as an economic model that would meet the requirements of the CBCPM. Using more than 200 input variables and 480 total parameters the CBCPM is a highly sophisticated model which requires detailed knowledge to be appropriately applied. Standard inputs are available to simplify usage. Stochastically simulating growth, fertility, calving, lactation, death, feeding intake and requirements, nutrient partitioning and genetic traits, the CBCPM has the ability to accurately predict production for any herd size using any time step. The success of CBCPM is evident in the number of studies completed using its capabilities (Baker, 1991; Baker et al., 1992; Baker et al., 1993; Foy, 1993; Hart et al., 1993; Fioretti, 1994; Rantanen, 1994; Steffens 1994; Enns, 1995; Enns, 1996; Bolortsetseq et al., 1996; Hyde and Bourdon, 1998; Foy et al., 1999; Doyle, 2000; Teague and Foy, 2002; Shafer, 2003).

Tess and Kolstad (2000a) developed a generalized model of range beef cattle production capable of accounting for diverse genetic types in response to changing forage quality and management strategies while accounting for interactions between genotype, forage quality and physiological state of animals. Output of the model is structured in terms of economic performance of the system under different breeding and management strategies. Using a complete and complex set of body composition prediction equations, growth and resulting requirements are predicted deterministically. Fat weight, lean weight, and intestinal fill are individually calculated to arrive at daily weight. Forage quality or amount of available nutrients in feedstuffs are input as metabolizable energy, neutral detergent fiber, and crude protein per kilogram dry matter, ruminally degradable protein per kilogram of crude protein. Daily requirement of metabolizable energy becomes a function of daily weight and available feedstuff energy. The model will allow the user to parameterize some phenotypes, including weight and weight gain. However there is no explicit opportunity to account for genetic potential of animals. Stochastically modeling fertility, age of puberty and probability of conception are both used to predict reproduction. Randomly assigned day of estrous and normally distributed probability of being bred, accounting for postpartum interval and calving difficulty of previous calving event, assign reproductive status of females (pregnant or non-pregnant).

In the companion paper by Tess and Kolstad (2000b), the model previously described was evaluated for usefulness. Due to the lack of a complete data set with all necessary model inputs for multiple production circumstances the model could not be validated as a whole, instead logic and assumption were critiqued. The populations used for evaluating the model included a herd raised under northern great plains range conditions described by Reynolds et al. (1990, 1991) and MacNeil et al. (1994) and the Beefbooster Cattle Alberta, Ltd. (Calgary, Canada). The Montana herd consisted of crossbred females (Angus-Herford, Pinzgauer-Herford, Red Poll-Hereford and Simmental-Hereford). The Beefbooster population consisted of 5 different composites, 3 made up of maternal breeds, 1 selected for calving ease and a terminal-sire line. While neither herd had all the inputs necessary to run the simulation model, together there was sufficient information. Each herd did have individual weight information, the forage availability and nutritional aspects were entered as average northern plains values where exact measures were unknown. Partial agreement was found between the two test populations actual weights and simulated weights. However the model overestimated intake of range forage and change in body condition over the year. Tess and Kolstad concluded it to be necessary to know or have fairly accurate values for crude protein, dry matter digestibility and per animal availability of dry matter (kg) to accurately predict performance.

Bourdon (1998) coined the phrase, sire selection by simulation, as a possible usage for beef cattle production models. Pointing out the downfalls of both selection index and simulation modeling, Bourdon (1998) advocated sire selection by simulation as a possible method to leverage the strengths of each to assist producers to make genetic progress. Selection for multiple traits simultaneously is necessary for genetic gain to be maximized. Derivation of economic values has traditionally been a serious problem for multiple trait economic selection. The value assigned to individual traits can vary based upon the current level of production (Enns et al., 2005). The selection index solution to this problem has been to derive profit equations, sometimes quite complex, and differentiate these for each trait in the objective. Model and simulation programs have approached the problem as allowing the prediction equations to simulate each traits effect. The bio-economic models can be more in-depth, accounting for relationships among traits, but they still necessitate parameterization which can introduce unwanted error. Using what he terms physiological breeding values, the additive genetic potential of an individual, Bourdon outlines a five step program of identifying the best candidates for selection. Instead of offering a single animal as the best candidate, an ideal biotype of what would be most beneficial is output to the user. Sire selection by simulation was shown to have the advantage of being dynamic, able to predict a future optimum genotype versus a selection index which predicts genetics in the present time and has no final “goal” for the user. A chief disadvantage to the ideology is the necessity for a complete bio-economic model including flexible yet rigorous simulation of biology, management and ease-of-use.

Decision Support Systems

Decision support and expert systems are both examples of intelligent support systems. These types of computer models allow users to interact to achieve some knowledge or summary to answer a question. Expert systems mimic a human expert or specialist to answer some specific question illustrating the tendency to be narrow in their capability, dealing with only a single area and able to give explanation for the reasoning (Lynch et al., 2000). An example of an expert system in agriculture is to answer the question of whether or not a farmer should spray pesticides or apply fertilizer. An expert system has in depth knowledge of a narrow subject matter. Decision support systems (DSS) are broader in scope compared to expert systems. Typical DSS employ a whole system approach where an entire production scheme is modeled from many details but only summarized results are reported back to the user. The use of quantitative versus qualitative information is the fundamental difference among expert versus decision support systems (Luconi et al., 1993)

The history of decision support systems traces back to the 1970’s coinciding with development of computers. Following a natural progression, as computers became available methods to use them in business and industry progressed. Modeling systems to predict outcomes or alternatives began to emerge. DSS have been developed for a variety of different disciplines including marketing, engineering, finance, accounting, ecology and military applications (Sprague, 1982). These systems were developed to provide objective recommendations as to what the best decision would be accounting for all affecters and interactions included in the system.

Many different frameworks for the development of these systems have been proposed. One such framework which has remained over time is that described by Sprague and Carlson (1982). In the book titled 'Building Effective Decision Support Systems' the authors describe a four step process to build robust, useable DSS. These four steps include: preliminary study and feasibility assessment, development of DSS environment, development of initial specific DSS and development of subsequent specific DSS. The development process is outlined from the view of three groups who will be involved with the system, the user, the builder and the tool smith. Throughout the development process feedback between and amongst the three groups involved in the DSS is crucial. Sprague advises the inclusion of all participating groups be part of all facets of development. If users are not included in the development phase there is a lack of ownership felt which ultimately may result in lack of use.

Acceptance and usage of DSS in agriculture has been problematic. In a review of attributes necessary for agriculture DSS Newman et al. (2000) suggests eight reasons for failure of agriculture DSS systems

1. Limited computer ownership among producers
2. Lack of field testing
3. No end user input proceeding and during development of DSS
4. DSS complexity and possibly considerable data input
5. No reason seen for changing current management methods
6. Distrust for the output of a DSS because producers do not understand the underlying theories of the model
7. Mismatch of the DSS output with the decision-making style of the producer because the producer's conceptual models are excluded
8. Unclear definition of beneficiaries (e.g., scientists, primary producers, and technology transfer agents)

In addition to the vested interest of users, ease of use can be compromised if they are not included very early in the development. In the realm of beef cattle breeding, technology acceptance and usage has been slower than that of other livestock industries. This may be due to several reasons, computer usage given the average age of producers as well as lack of transparent systems producers are able understand (Newman et al., 2000).

The successes of DSS are dependent on several factors. These include if the system meets the user's needs, commitment of developers, ease of use, and support from management (Newman and Stewart, 1997). Ultimate success of any system depends on a champion to carry the project through and maintain it. Lacking a champion, each system seem relegated to history (MacNeil et al., 1998).

Beef Cattle DSS

The focus of many DSS for beef cattle has been predicting and comparing different crossbreeding systems or breeds. Some examples of DSS systems that have been developed for beef producers are HotCross (Newman et al., 1997), SIMUMATE (Minyard and Dinkel, 1974), Decision Evaluator for the Cattle Industry (DECI) (Jenkins and Williams, 1998) and BREEDOBJECT (Barwick et al., 1995).

HotCross was developed by Newman et al. (1997) to simulate crossbreeding performance in tropical and sub-tropical environments of Northern Australia. Using literature estimates of heat and disease tolerant cross-bred animal's performance, a database was assembled to calculate predicted performance in a particular location in Queensland, Australia. Users are asked to input a base cow breed composition, farm location being grazed and level of nutrition. The predictive portion of the system first calculates performance based solely on the tropical environment, accounting for direct and maternal breed effects and direct and maternal heterosis. This performance prediction is then adjusted by a cross specific factor accounting for environmental stressors (region and nutrition). Also factored into the final predication are adjustments for tick, worm and heat stress. Users of HotCross are shown potential performance differences from breed choice in their own environmental conditions.

SIMUMATE (Minyard and Dinkel, 1974) was an early model which was able to compare different crossbreeding systems and different breeds under specific production circumstances. Individual management and feed resource parameters were identified by producers either through completion of a survey or through one-on-one interaction with extension agents. Once these input parameters were collected they were sent for analysis and interpretation at South Dakota State University (Newman and Stewart, 1997). Using available feed to scale carrying capacity based upon predicting requirements for maintenance, milk production and weight gain crossbreeding systems could be compared. SIMUMATE had the ability to predict net returns at different endpoints including, weaning, after backgrounding, after finishing and at harvest. (MacNeil et al., 1998)

The DECI simulation model (Jenkins and Williams, 1998) uses a modification of the TAMU model. The DECI system allows producers to enter herd parameters at a fairly high level of detail. DECI models a herd using a daily timestep, adjusting for weight gain/loss on an individual animal basis. Management decisions, such as culling strategies or plane of nutrition, as well as genetic potentials, such as time of calving or postweaning growth, can be evaluated. The user is returned a variety of graphs and reports from the simulation. Changes over time can be compared from differing management differences, or economic and phenotypic factors

BREEDOBJECT (Barwick et al., 1995) is an Australian designed DSS tool which produces customizable selection indexes to return dollar figure comparisons of potential sires. BREEDOBJECT was designed to work together with BREEDPLAN estimated breeding values. Users have different options of how they can interact with BREEDOBJECT. For breeders not wishing to enter their own personal parameters a series of 20 breed, market and economic combinations are made available to produce generalized selection indexes. These are known as ‘Breed-Level $Indexes’. Alternatively users can choose to fill out a questionnaire from a web interface with details of their marketing, production levels, cost levels and type of environment to customize the index for their particular production schema. BREEDOBJECT has the ability to extend to include several different regions of Australia as well as different crossbreed combinations. Based upon the input parameters index values are immediately available to users to rank potential sires (http://breedobject.com/static/About_BreedObject.html, accessed Sept. 1 2011)

DSS and Simulation models of other species

Simulation production models and DSS have been completed for all livestock species and many agriculture crops. Each species has its own unique aspects which change modeling criteria or requirements. Modeling livestock species such as swine, chicken or dairy is different than beef or sheep in that much more control over production inputs and individual production outputs are available. Due to the intensive nature of confinement production, ie; fed versus grazed and housed versus open range, economic costs within these production systems are easier to quantify. Similarly modeling crop species is much different than livestock. In some cases crop producers have more control over elective practices such as application of pesticides or herbicides, control of water (irrigated or dry land), but the cost associated with these decisions can greatly effect overall profitability. DSS is a useful tool for crop producers to weigh the cost benefits of such practices.

In a review of agronomy DSS, McCown el al. (2002) outlined eight different systems developed for different crops and their usage over time. The DSS reviews included wheat, cotton and grazing systems designed for simulating and offering recommendations for fertilizer application, pesticide use, growth potential, weather conditions, yield and economic implications. One such system which received a lot of attention by both producers and the scientific community is COMAX/GOSSYM expert system and decision evaluator (McKinion et al., 1989). Designed for cotton farming in the southern United States it has been used successfully in a variety of environments. The synergistic pairing of two systems, GOSSYM was built to model cotton growth and yield while COMAX evaluates fertilizer and irrigation options. GRAZPLAN (Donnelly, et al., 1996), an Australian animal grazing simulation, includes a suite of several different DSS modules (GrassGro, GrazFeed, etc.) for different aspects of production. To simplify operator inputs a variety templates are available for users to select from to lessen the burden of user/computer interaction (McCown, et al., 2002). Designed to be tied to a weather data base, GRAZPLAN has routines to predict pasture growth and feed intake and production of animals grazing and offer best combination of stocking rates, grazing duration, as well as inputs into the soil.

Faust et al. (1992) described a swine simulation model in which a three-tiered production system was simulated using five genetic strains. The stochastic model included prediction of gene flow from each of the tiers though the production chain. The three tiers include nucleus, multiplier and commercial with five genetic lines including maternal, F1 line, three-breed-cross market hogs and 3 three nucleus lines: maternal grand-dam, maternal grandsire and terminal sires. To mimic typical United States swine production replacement animals for the multiplier tier came from the nucleus, commercial replacements came from the multiplier and nucleus replacements were top individuals from within the nucleus. Simulated phenotypes included number born alive, average daily gain, backfat at 110 kg, conception rate, feed per gain, survival rate, number weaned, days from weaning to 110 kg, age of puberty for females, growth rate and weight. Replacements were selected based on within tier three trait (number born alive, average daily gain and backfat at 110 kg) selection index merit values. The results of an example ten year simulation showed greatest genetic change and profit from sale individuals was in the nucleus tier and lower in sub-tiers.

New Zealand dairy production been simulated in several publications. Lopez-Villalobos et al. (2000) developed a deterministic model which simulated dairy herds’ nutritional, biological and economic performance. Age structure was simulated using a Markov chain of the probability of survival.

$$d_j = \prod_{i=2}^{j} s_j / \sum_{k=2}^{10} \prod_{i=2}^{k} s_i$$

Age classes were simulated from 2 to 11 years old, with each successive age group decreasing according to the probability of becoming pregnant, death, disease, and suitability for dairying. All cows 11+ years old were culled. Nutrient requirements were simulated on an annual basis of the animal to include lactation, gestation, maintenance and growth. Simulated crossbreeding among three breeds was evaluated for profitability.

Similar to the previously described TAMU beef production model, a TAMU sheep production model was created by Balckburn and Cartwright (1987). Using a modified version of the TAMU sheep production model Wang and Dickerson (1991a) simulated wool and lamb production with varied genetic potentials and production systems. This simulation model is capable of simulating production under optimum energy (intake requirements being fully met) as well as under energy restriction. Differing genetic potentials of mature size, fertility, wool growth and growth can be modeled. Additionally cost and revenue of feed, wool, lamb and cull ewes; individual animal or whole flock simulation; strait breed, crossbreed, composite or terminal-sire systems options can be simulated (Wang and Dickerson, 1991b, c).

Simulating sheep production in the hill country of the United Kingdom, Conington et al. (2004) developed a model to derive economic values of differing combinations of carcass and maternal traits. Three different farm types were simulated, intensive, semi-intensive and extensive, with varying quality of pasture available. Considering ten traits, economic values were derived independently through simulation of a flock to through a single year. Results showed greater economic value of genetic improvement in harsher environments versus environments where nutritional requirements were easily met.

Summary

Simplification of multiple trait selection in terms of an index or simulation rankings is a valuable tool for breeders. Generalized selection indices are already available to producers, but a customizable DSS capable of simulating an individual’s production circumstances would be of greater benefit. To be valuable a DSS must be simple yet robust to user’s needs (Newman, 2000). While simulation models have been extensively researched and validated in the literature, many are too technical and detailed for producer usage. A alternative use for simulation models are as background engines paired with a DSS which will return a custom derived rankings of animals.

Chapter III

MATERIALS AND METHODS

Overview

A deterministic model designed to simulate outcomes of sire selection on a whole herd basis in a beef cow-calf operation was constructed. The model was developed to simulate predicted annual production of a cow-calf operation using different sire genetics. Female animals are simulated from the user defined parameters based on current average performance. From user entered parameters a current/base herd is generated as if the herd were to make no genetic change in the generation of the next calf crop. Matings are simulated using chosen sires and the defined cow herd and the resulting offspring represent the sire's overall genetic contribution to the cow herd. With the deterministic approach the simulated herd is assumed to be comprised wholly of the daughters resulting from this simulated mating. Genetic merit of these daughters and their resulting progeny are one half the sires breeding value added to one half the average dams breeding value.

Cow herd production is divided by female age classes, two years of age though the user defined maximum age. Each age class is modeled independently. The division of the cow herd into separate age classes allows the model to discriminate between production levels of younger females versus older females as well as account for differences in nutritional requirements of young versus old animals. Since the "new" herd is modeled as a herd representing the average daughter of sires used, the simulated cow herd is a combination of the sire and base herd genetics for all traits. Using the age class approach, each trait is simulated individually and results are accumulated and passed to other dependent simulation sub-routines. The general sequence of calculations begins with formulation of the age structure, calculation of pregnancy rates and requirements for energy, prediction of calving ease, and lastly calculations of cost, income, and profit.

The Model

Written in version 7.2 of APL (APL2000 Inc., Rockville, MD) the model is compatible with any external interface accepting a comma delimited file of input parameters and able to output a comma separated file of simulated values. The web interface for this model was created through a separate project and allows a vehicle for users to input parameters required for the simulation. The details and description of the web programming are not included in this thesis.

The model was developed using small functions, each simulating different components of production. The input information for the model is passed in the form of model parameters and selected bull EPD. Input parameters are restricted to logical and sensible boundaries based on industry averages and ranges. These checks are in place to assure the functionality and accuracy from the simulation model. For example probability traits such as heifer pregnancy are required to be at a sufficient level for a herd to produce enough replacements to maintain herd size. The order in which the segments are organized allow sequential prediction of production, the output of each segment is the input of the next segment.

Model Structure

Five primary components and varying functions make up the simulation model:

1. Age structure
    a. Reproduction
        i. Mixed age stayability
        ii. Heifer pregnancy
    b. Culling

    c. Herd replacements
2. Growth
    a. Weight phenotypes
3. Nutritional requirements
    a. Maintenance requirements
    b. Growth requirements
    c. Lactation requirements
    d. Gestation requirements
4. Calving ease
    a. First calf heifers
    b. Mixed age cows
5. Economics

User Inputs

The primary goal in the development of the model was to remain as robust as possible while requiring the fewest user inputs necessary. Inputs are split into four categories, production, management, economics and genetics. A complete list of input parameters and acceptable ranges is given in table 3.1. All user inputs are pre-populated with industry average values, users are asked to complete as much information as they possibility can. The model will give a result for any set of inputs so as long as they are within the acceptable range. However to be actually useful to a user, the more accurate the inputs the more accurate the simulation will be.

The first step in the simulation is to construct a baseline level of production modeled using only the input parameters assuming no changes in genetic or performance levels. The results serve as the baseline for all future comparisons.

Table 3.1. User inputs used to parameterize cow-calf DSS

User Input	Definition	Valid range of values
Production Tab		
Herd Size	Size of simulated herd	20 to 999,000
Heifer Calving Rate	Percentage of heifers conceiving and birthing a live calf	50% to 99%
Mixed Age Calving Rate	Percentage of mixed age cows (2yr and older) conceiving and birthing a live calf	25% to 99%
Mature Weight	Average weight (lbs.) of a seven to ten yr old cow	1.2*ywt to 2,000
Calf Survival Rate	Percentage of calves weaned	50% to 99%
Yearling Weight	Average weight (lbs.) of a one year old offspring	1.2*wwt to 1,200
Weaning Weight	Average weight (lbs.) of a 205d old offspring	2*bwt to 700
Birth Weight	Average weight (lbs.) at birth of offspring	40 to 200
Heifer Calving Difficulty	Percentage of heifers requiring some assistance at calving	1% to 50%
Management Tab		
Constant Input	Constraint to maintain current feed input or vary herd requirements	
Breeding System	Terminal/Maternal – Option to simulate single generation or herd genetics becoming sire daughters	
Replacements	Bred/Buy – Option to replace animals with female calves within the herd or buy from an external source	
Cows Per Bull	Number of cows exposed to each bull	1 to herd size
Maximum Cow Age	Age at which females are culled regardless of production	8 to 15

Economics Tab		
Incremental Cow Costs	Fixed cost, per head, for items such as ear tags, vaccinations, etc.	0 to 500
Capital Value of Heifers	Average market value of heifers	0 to 10,000
Capital Value of Cows	Average market value of cows	0 to 10,000
Capital Value of Bulls	Average market value of bulls	0 to 10,000
Heifer Price	Market price cull heifers will be sold at	0 to 500
Cow Price	Market price cull cows will be sold at	0 to 500
Calf Price	Market price weaned calves will be sold at.	0 to 500
Cost of Replacement Heifers	Current market price of yearling females for replacement. Only used If replacements are to be purchased.	0 to 2,000
Incremental Feed Costs	Current market price of feed, per ton. Only used if ‘constant output’ is set to feed and herd requirements exceed ranch production	
Discount Rate	Interest rate charged on borrowed capital.	
Cow Genetics Tab		
Cow Breeds	Average breed composition of the cow herd, measured in 1/8 increments	Must sum to 1
Average EPD of all cows in the herd for ERT’s used in the model including: Birth Weight, Weaning Weight, Yearling Weight, Milk, Calving Ease Direct, Heifer Pregnancy, Calving Ease Maternal, Stayability and Maintenance Energy EPD		

EPD

As designed, the model uses only economically relevant trait EPD listed in table 3.2. Although not all breeds have these EPD published, this list was identified as the ideal suite of EPD necessary to predict the major segments of genetic merit. In the case of missing or non-existent EPD for traits used by the model a zero value is default.

Table 3.2. Economically relevant trait EPD used in DSS model.

Trait	Definition
Calving Ease Direct	Probability of a calf being born unassisted to a two year old heifer
Calving Ease Maternal	Probability a bulls two year old daughter's will calve unassisted
Birth Weight	Expected difference in pounds of weight at birth
Heifer Pregnancy	Probability a heifer will conceive to calve at two years of age
Maintenance Energy	Expected difference in mega-calories per month of energy necessary to maintain body weight
Weaning Weight Maternal (Milk)	Expected difference in pounds of weaning weight a bull's daughter will produce attributed to milk production
Stayability	Probability a female will remain productive in the herd to six years of age
Weaning Weight	Expected difference in pounds of weight at weaning (205d)
Yearling Weight	Expected difference in pounds of weight at yearling (365d)

Threshold traits included in the simulation include calving ease direct and maternal, heifer pregnancy and stayability. EPD published for these traits are reported on a probability scale which is based upon a deviation from a 50% probability; however to be useful for biological modeling, these are transformed to the underlying scale. The underlying scale assumes a normal distribution with a mean of zero and standard deviation equal to that of the trait being transformed. These standard deviations are presented below in table 3.3. To accomplish the transformation to the underlying scale EPD are first normalized to a mean zero and their respective standard deviation. These normalized values are then used as the truncation point for integrating the area of the curve to solve for the corresponding underlying value. Threshold traits on the underlying scale appropriately account for prior level of production, having a greater effect on low producing herds and less effect on higher producing herds (Enns et al., 2005).

Table 3.3. Standard deviations of threshold traits used to convert probability EPD to the underlying scale.

Threshold Trait	Standard Deviation
Calving Ease Direct[1]	-0.6595
Calving Ease Maternal[1]	1
Heifer Pregnancy[2]	1.17
Stayability[2]	1.17

[1] – Quaas et al., 1998

[2] – Phenotypic standard deviation of 2004 RAAA database

Age Structure

Age structure is predicted using the calving rates of mature cows and heifers and the user defined maximum age. The user defined (base herd) mixed age calving percentage (**bMCP**) and heifer calving percentage (**bHCP**) values are assumed to be the percentage of females which will calve that year. All cows without a calf are assumed to be sold from the herd at weaning. The number of cows per age group is derived from the sequential probability a cow will calve each year, from two years of age to the point of user defined maximum age. Mandatory culling of old cows is fixed at 100%, 75%, 50% and 25% of four oldest age groups respectively. Assuming mixed age calving percentage is the average of all cows ages 3 to maximum age, age structure for these animals are calculated first followed by heifers. Construction of the base herd age structure and the subsequent predicted herd's age structure is presented below in a 4 step process.

Step 1

Given the user input mixed age calving percentage (bMCP), heifer calving percentage (bHCP) and maximum age (bMA), the age structure is assumed to be a constant proportion of these values. Inconsistency of these fixed proportions such as voluntary culling, herd reduction and death loss are not accounted for. The number of cows in any particular age class is a function of the mixed age calving rate calculated as the sequential probability of remaining in the herd for any number of consecutive years. Given by the equation:

$$AC_i = bMCP^{(i-2)} * \frac{HS}{\sum_{i-2}^{bMA} bMCP^{(i-2)}}$$

where:

$i = 3 < i < MA$

AC_i = Age class of cow

$bMCP$ = Mixed age calving rate

HS = User defined herd size

bMA = User defined maximum age

Step 2

The second step in simulating predicted age structure is to calculate the phenotypic stayability of the base herd given the age structure formed in step 1. Stayability is defined as the probability of a cow will remain in the herd to six years of age assuming she was first breed to calve at age 2 or the proportion of 2 year olds to 6 year olds. The base herd stayability can be expressed as:

$$bSTY = \frac{AC_2}{AC_6}$$

where:

$bSTY$ = base herd stayability

AC_i = Age class of cow

Step 3

From the calculated base herd stayability, a potential bull's stayability EPD is combined to form a prediction of the age structure. Working with both stayability values on the underlying scale, the base herd's phenotypic stayability and the bull's stayability EPD are additive. Using the predicted stayability, where the entire herd became daughters of the potential bull, a reverse method can used to recalculate the mixed age calving percentage. The relationship between predicted mixed age calving percentage and predicted stayability is given by the equations:

$$pMCP_i = pSTY_i^{0.25}$$

where:

$i = 3 < i < MA$

$pMCP$ = Predicted mixed age calving percentage of bull i

$pSTY$ = Predicted stayability of bull i mated to base herd

Step 4

Using the predicted mixed age calving percentage in the same formula as step 1, a predicted age structure is formed representing a herd composed of the bulls' daughters. Predicted number of cows in a particular age class is calculated from:

$$pAC_i = pMCP^{(i-2)} * \frac{HS}{\sum_{i-2}^{bMA} pMCP^{(i-2)}}$$

where:

$i = 3 < i < MA$

pAC_i = Predicted number of cow's in age class i

$pMCP$ = Predicted mixed age calving rate

HS = User defined herd size

bMA = User defined maximum age

Heifer pregnancy

In the simulation all heifers are given the opportunity to calve as a two year old. Heifer pregnancy is calculated from the user defined heifer calving rate assuming all heifers not pregnant are sold from the herd as yearlings. Using the age structure previously described, the number of heifers is calculated from the equation:

$$bAC_1 = \frac{bAC_2}{bHCR}$$

where:

bAC_1 = Number of heifers (age class 1)
bAC_2 = Number of two year old cows (age class 2)
$bHCR$ = User defined heifer calving rate

The user defined heifer pregnancy rate and the bulls contribution to daughter heifer pregnancy is additive on the underlying scale, ranging from 25% to 99% heifer pregnancy. These two values together with the respective bulls' age structure value and heifer calving rate are used to determine the number of replacement heifers required.

Replacement Constraint

Replacements can be bought or developed depending on the user's choice. Regardless of the user's decision, the model assumes replacement females are the same genetic merit as the calves produced from the base herd. The implications of either choice can ultimately affect the revenue stream of the system. If replacements are developed from female calves born in the herd, 'Bred' option, the system is charged for feed requirements required for the growth and maintenance of these animals. Breeding replacements also decreases the income of the system because female replacements are assumed to come from females calves that would otherwise be sold at weaning. If the ‘Buy’ replacement option is implemented all female calves are sold at weaning and replacement yearlings are charged to the system at the price input by the user.

Growth Curve

In order to predict weight phenotypes and subsequent feed requirements, growth was modeled from birth (day 1) to mature weight (day 2,190). A growth curve is fit using six points or knots: user defined average weights at four points, birth weight, weaning weight, yearling weight and mature weight as well as two computed points, two and three year weight. Using spline methodology five separate line segments are fit; birth to weaning, weaning to yearling, yearling to two year old, two year old to three year old and three year old to mature, such that each is independent of each other. Each of the five line segments allow for differing gain over time. The slope of each segment is calculated from the average daily gain over the respective time period.

Segment 1 – birth to weaning:

$$m_1 = \frac{bWWT - bBWT}{205}$$

Segment 2 – weaning to yearling:

$$m_2 = \frac{bYWT - bWWT}{165}$$

Segment 3 – yearling to 2 year old:

$$m_3 = \frac{\left[bYWT + \left(0.6 * \ (bMWT - bYWT)\right)\right] - bYWT}{365}$$

Segment 4 – 2 year old to 3 year old:

$$m_4 = \frac{\left[bYWT + \left(0.8 * \ (bMWT - bYWT)\right)\right] - \left[bYWT + \left(0.6 * \ (bMWT - bYWT)\right)\right]}{365}$$

Segment 5 – 3 year old to mature weight:

$$m_5 = \frac{bMWT - \left[bYWT + \left(0.8 * \ (bMWT - bYWT)\right)\right]}{1{,}446}$$

where:

m_i = slope of segment i

$bBWT$ = user defined average birth weight

$bWWT$ = user defined average weaning weight

$bYWT$ = user defined average yearling weight

$bMWT$ = user defined average mature weight

Connecting these segments into a single curve, each segment uniting exactly at the knot of the previous segment, results in a curve that exactly matches the user’s actual weight entries. An example of this growth curve is given in figure 3.1. From this growth curve, prediction of daily weight as well as daily gain from birth to mature weight is possible. At maturity animals are assumed to maintain constant weight. Modeling a growth curve in this manner makes the assumption that the ranch has been operating at these (user defined) growth rates for a significant time period and it is able to continue to operate at this growth performance level.

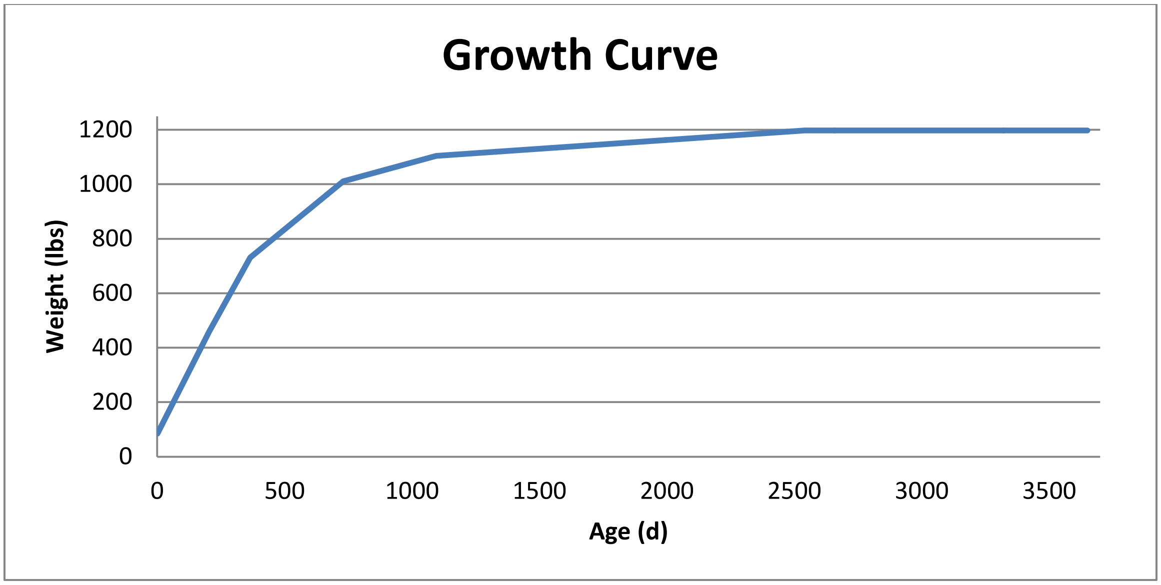

Figure 3.1. Simulated growth curve assuming the following knots: BWT = 85, WWT = 500, YWT = 775, MWT = 1,200

Weight Phenotypes

Input values for weight traits include averages for birth, weaning, yearling and mature weights. These average herd weights are used to establish the base herd and subsequent predicted herds growth potential. EPD for all weight traits, with the exception of mature weight which is discussed separately, and weaning weight maternal are additive to the user input average weights projecting the positive or negative change the average weight phenotypes of predicted herds.

Of the user weight inputs, weaning weight direct and weaning weight maternal are the most vital as it affects the largest number of variables. Average weaning weight influences maintenance and growth requirements of calves as well as revenue generated from sold calves. Weaning weight maternal effects the requirements for lactation as well as revenue from calves sold. Weaning weight is adjusted for both age of dam and sex of calf (table 3.4). Age of dam adjustments are added directly to the weaning weight depending on the parity of the dam as recommended by the Beef Improvement Federation (2002). Sex of calf adjustment are based on a percentage of a calves total weaning weight. This approach was taken to avoid a bias of rewarding or penalizing heavier or lighter weaning weights.

Table 3.4. Weaning weight age of dam and sex of calf adjustment factors

	Age of Dam Adjustments				
AOD	2 yr	3 yr	4 yr	5-9 yr	10+ yr
BIF Adj.	-57	-38	-19	0	-19
	Sex of Calf Percentage Adjustments				
Males	0.91	0.94	0.97	0	0.97
Females	0.92	0.94	0.97	0	0.97

User input yearling weight similarly affects a variety of parameters within the model such as the sale weight of cull heifers and the maintenance and growth requirements of yearling animals. Mature weight of the average cow within the herd is used to predict the total feed requirements of a mature cow and the revenue from cows culled from the herd annually.

Due to the lack of a mature weight EPD by any breed association at the time of this project, the only prediction available is the maintenance energy EPD which uses mature weight as a component trait. In order to account for changes in mature size a potential bull's maintenance energy EPD is partitioned back into milk and mature weight components thus allowing for prediction of future cow sizes. The maintenance energy EPD of potential sires would have originally been calculated from the following equation (Evans, 2001):

$$ME_i = 0.5\left((MW_a)(MW_i) + 0.10 * MK_i\right)$$

where:

ME_i = Maintenance energy EPD

MW_a = Breed Average Mature Weight EPD

MW_i = Mature Weight portion of EPD

MK_i = Weaning Weight Maternal/Milk Portion of EPD

From the four user defined average weights and the respective EPD for each, the predicted phenotypes of the bulls daughters is created. These phenotypes play a major role in many aspects of the subsequent model routines.

Energy Requirements

Energy requirements are calculated based on four components: maintenance requirements, growth requirements, lactation requirements and gestation requirements. For each of the physiological states, requirements are calculated for an average animal of a particular age class and extrapolated over all animals in that age class No variation within age class is present. Age class requirements are summed to result in total herd requirements. Requirements of pre-weaning calves are assumed to initially be met by the mother's milk yield progressively consuming additional forage as body weight increase.

Each of the requirements is calculated for the user defined base herd and for each subsequent herd representing various bull use choices. Impact of a bull choice is determined using EPD for birth weight, weaning weight, yearling weight, mature weight, milk and maintenance energy.

Maintenance requirements

Maintenance requirements are defined as the amount of energy (Mcal) required to maintain and sustain basal biological activity for an individual animal. The AFRC equation used to calculate the amount required is (Alderman and Cottrill, 1993):

$$M_m = C_1\left(0.53\left(\frac{W}{1.08}\right)^{0.67}\right)$$

where:

C_1= Sex correction factor - 1.15 for bulls and 1.0 for cows

W = Weekly average body weight

Growth Requirements

Growth requirements are defined as the amount of energy (Mcal) required for growth of an individual. Daily growth is derived from the fitted growth curve in the model over the lifetime of the animal. The AFRC equation (Alderman and Cottrill, 1993) used to simulate these growth requirements is:

$$EV_g = \frac{C_2(4.1 + 0.033W_1 - 0.000009W_1^2)}{(1 - C_3 * 0.1475W_2)}$$

where:

C_2=Mature size & sex correction factor

C_3= Plane of nutrition factor (equal to 1 when requirements are met)

W_1= Weekly average weight

W_2= Weekly average gain

Lactation Requirements

Lactation requirements are defined as the amount of energy (Mcal) required by each cow to provide required growth for each calf. Predicted calf growth is derived from the growth curve of an animal within the herd from day 1 to day 205. The AFRC equation used to simulate these requirements (Alderman and Cottrill, 1993):

$$M_1 = \frac{\left(Y * \ (0.0384[BF] + \ 0.0223[P] + \ 0.0199[LA] - \ 0.108)\right)}{k_1}$$

$$Y = 2.82 * (1 + \ 0.017 * WWM) + \ 0.06$$

where:

Y = Daily milk yield (Wood’s lactation function)

BF = Butterfat equal to AFRC average for beef cows 36g/kg

P = Crude Protein equal to AFRC average for beef cows 32g/kg

LA = Lactose equal to AFRC average for beef cows 50g/kg

k = Efficiency of utilization (0.563)

WWM = Weaning weight maternal EPD

Gestation Requirements

Gestation requirements are defined as the amount of energy (Mcal) required by each cow to carry a single calf from conception to birth (285 days). The AFRC equation used to simulate these requirements:

$$E_c = 0.025W_c(E_t * 0.0201e^{-0.0000576t})$$

$$log_{10}E_t = 151.665 - 151.64e^{-0.000057t}$$

where:

W_c = calf birth weight

t = time in days

Feed Constraints

A user choice defines how energy requirements are partitioned from a “whole herd” perspective. If the user chooses the ‘Feed’ constraint, the simulation scales the predicted herd size to equal the total mega-calories (Mcal) consumed by the base herd. Working under the assumption that the ranch system is working at its full capacity and all necessary requirements are being met for the base herd with no additional energy/feed used from outside of the operation. This total annual energy amount is used to scale the number of cows in the predicted herd to use the identical amount of Mcal as the base herd. If the simulated herd consumes less feed, the number of productive females is increased versus the scenario where the new herd consumes more feed resulting in a reduction in productive cow numbers.

The second user option, ‘Cows’, fixes the number of productive females. In turn the total amount of feed required increases or decreases to meet the requirements of the cow herd. If the amount of Mcal required for a predicted herd is greater than that of the base herd, feed is assumed to be purchased at a user defined price. The average energy value of the purchased feed is assumed to be the 4.19 Mcal per kilogram (average value from the NRC for grass hay; NRC, 2000). If a predicted herd requires fewer Mcal than the base herd the feed is assumed to be sold at the same value at the user defined price.

Calving Ease

As with stayability and heifer pregnancy, calving ease is modeled on the underlying scale. The user defined heifer calving difficulty parameter, percent assisted births, is used as the baseline for ultimately calculating difficulty for individual age groups for each sex of calf. It is assumed within the simulation that the proportion of male to female calves is equal. Male calves born to heifer mothers have the greatest probability of requiring assistance with a declining probability for each dam age class with female calves born to heifers and later parities following the same trend. The probability of assistance for cows three, four, five, six year old and seven years old and greater are presented in table 3.5. The relative difference across age of dam within sex class or sex class within age of dam can be interpreted as the increased or decreased probability of requiring assistance. These values are calculated using values reported by Quaas et al. (1988) under the assumption that the probability of requiring assistance decreases as parity increases. These values define the distribution mean of the probability curve of requiring assistance at birth.

Table 3.5. Underlying mean standard deviation of calving difficulty[1]

Calf Sex	Dam Parity					
	2yr	3yr	4yr	5yr	6yr	7yr+
Males	-0.66	0.223	0.66	1.017	1.106	1.22
Females	0	0.774	1.209	1.519	1.664	1.797

[1] – Adapted from Quaas et al., 1998

The underlying probability of calving unassisted is converted to an observed probability giving the expected number of calves born unassisted. The number of assisted births is calculated from one minus the number of unassisted. In addition 10% of calves experiencing dystocia are assumed mortalities.

Breeding System

Besides being able to evaluate bulls, the user has the ability to select either a ‘Terminal’ or ‘Maternal’ breeding system. The simulation has the ability to predict a onetime calf crop under the terminal option. This onetime mating assumes the only genetic difference between the base herd and predicted herd are from the traits birth weight, weaning weight and calving ease direct. The terminal option would be analogous to breeding to a bull and not keeping any of his daughters. The default maternal option utilizes all EPD and accounts for genetic merit of daughters of the selected bull as outlined previously.

Economic Assessment

Economic assessment of a bull’s effect on the base herd’s performance is dependent upon eight sources of income and costs (table 3.6). Income sources are derived from the sale of weaned calves and culled females. The total pounds of weaning weight available to sale is dependent upon if replacements are produced or purchased, survival rate of calves, average weaning weight and number of cows in later parities of production. The greater the number of cows in later parities is dependent upon the stayability and heifer pregnancy of herd. The total pounds of weaned calves by sex are summed over all cow age groups and valued subject to an adjusted to a sliding scale accounting for discounts and premiums associated with different weight classes of calves. Because of the forward nature of beef cattle pricing, a price slide is built into the model to account for potential sale weight differences. If the average weaning weight of calves in the predicted herd is different than the weight of the base herd the price slide adjusts the sale price appropriately. The user selects if the calves forward contracted and magnitude of the price slide, up or down, is applied to the predicted sale weight. The formula for the base herd total value of pounds of weaned calves is:

$$bTV = \sum_{i=3}^{MA} \left[\left(bWWT_{M_i} * N_{M_i} \right) * \left(P - \left(bWWT_{M_i} - bWWT_M \right) * S \right) + \left(bWWT_{F_i} * N_{F_i} \right) \right.$$
$$\left. * \left(P - \left(bWWT_{F_i} - bWWT_F \right) * S \right) \right]$$

where:

bTV = Total dollar value of weaned calves

MA = User defined maximum age

$bWWT_M$ = Average weaning weight of male calves in cow age class i

N_M = Number of male calves in cow age class i

$bWWT_F$ = Average weaning weight of female claves

N_F = Number of female calves in cow age class i

P = User defined calf price

In the case of predicted herds the total pounds of weaned calves are still summed by sex over all cow age groups and adjusted by a price slide shown in the formula:

$$pTV_X = \sum_{i=3}^{MA} \Big[\big(pWWT_{XM_i} * N_{XM_i}\big) * \big(P - (pWWT_{XM} - bWWT_M) * S\big) + \big(pWWT_{XF_i} * N_{XF_i}\big) * \big(P - (pWWT_{XF} - bWWT_F) * S\big) \Big]$$

where:

pTV_x = Total dollar value of weaned calves of sire x

MA = User defined maximum age

$pWWT_{XM}$ = Average weaning weight of male calves in cow age class i of sire x

N_{XM} = Number of male calves in cow age class i of sire x

$pWWT_{XF}$ = Average weaning weight of female claves in cow age class i of sire x

N_{XM} = Number of female calves in cow age class i of sire x

P = User defined calf price

$bWWT_M$ = User defined average weaning weight of adjusted for male calves

$bWWT_F$ = User defined average weaning weight of adjusted for female calves

S = Slide price

The revenue from the sale of cull females is partitioned into sale of cows culled due to age and pregnancy status. The number of cull cows is derived from the fixed culling proportions of the four oldest parity age groups. The number of open cows is dependent upon the mature cow calving rate, dictating the number of cows which will not have a calf and be sold from the herd. Open heifers are calculated in the same manner as open cows, but using the heifer calving rate instead. User defined sale prices for females allow for regional differences or projections in time.

Simulated costs are functions of fixed costs and calving difficulty. Fixed costs are defined as costs of owning an animal for one year. These costs include such items as ear tags, vaccines, but not items related to supplemental feed or veterinarian costs. Fixed costs differ for various age classes of animals, calves, heifers and cows. While fixed cow costs can be adjusted by the user, calf and heifer fixed costs are constant at $5 and $20 respectively. Feed costs are only levied if the number of cows is constrained (held constant) and base herd feed resources are not sufficient to meet annual requirements of a predicted herd. Calving ease is charged at a fixed rate of $25 for each instance.

Model Output

The model is designed to be run twice for a complete set of results. The first run is done only using the base herd input parameter to create the status quo and allow user interaction if a input was wrong. The second run uses the base herd parameter but also accounts for the genetics of the selected bull. Predicted results are a variety of economic values and animals per age class. These results are sums of the respective age classes they represent.

Table 3.6. Summary of Income and Cost factors

Source	Type	Driving Forces	Value
Sale of Weaned Calves	Income	Average Weaning Weight Calf Survival Rate AOD adjustments	User Defined price per hundred pounds
Sale of Cull/Open Cows	Income	Average Mature Weight Mixed Age Calving Rate Stayability	User Defined price per hundred pounds
Sale of Cull/Open Heifers	Income	Average Yearling Weight Heifer Calving Rate Heifer Pregnancy Rate	User Defined price per hundred pounds
Fixed Calving Difficulty Cost	Cost	% Assisted Births Stayability Heifer Pregnancy	$25 per instance
Fixed Calf Cost	Cost	Calf Survival Rate Mixed Age Calving Rate Heifer Calving Rate	$5 per calf
Fixed Cow Cost	Cost	Herd Size	User Defined price per head
Fixed Heifer Cost	Cost	Herd Size Heifer Pregnancy	1.25 * User Defined Cow Fixed Cost
Feed Cost	Cost	Constraining Cow Numbers Cow Maintenance Requirements	User Defined price per ton of feed

Chapter IV

RESULTS AND DISCUSSION

General output of the simulation

The general output of the model is a single value of merit of individual bulls selected for simulation termed net per bull. In essence it represents the difference in profitability of a herd that is totally comprised of that bull's daughters compared to continuing at current production level. This single value encompass the bulls' aggregate value of their entire EPD suite and long term genetic contribution to the herd through retainment of female offspring. It is presented to correspond to the user defined variable cows per bull, as the bull's overall profitability divided by the herd size and multiplied by the number of cows each bull would have been mated to. If desired, further details of the bull's impact on profit by specific herd parameters, e.g predicted weaning weight of progeny, female replacements, etc., can be viewed. The "drill down" nature of the program output offers a user the ability to compare, at the individual cow level, a bull's genetic effect on the current level of production. In the output all values are presented side-by-side to facilitate comparison to the base herd. The base herd assumes status quo production at a level identical to user inputs.

The first level of detail given to the user is a brief summary of simulation outputs. These include net value of each simulated bull for overall rank considerations. The second level of detail available is a breakdown of the number of females (predicted age structure), costs and income by parity compared to the base herd. This simulated age structure output drives many of the other predicted outcomes. A shift in age structure can have a large impact on the simulated herd. An upward shift in age structure, greater number of mixed age cows, will lead to a more productive herd. More mixed age cows will lead to:

1. Fewer replacements necessary to maintain herd size
2. Heavier weaning weights as mature cows are assumed to wean heavier calves
3. Decreased incidence of dystocia through a smaller proportion of first calf heifers in the herd
4. Overall higher calving rates (assuming mixed age calving rate is greater)

Heavier weaned calves and higher calving rates lead to increased revenue via more calves sold, less dystocia and fewer replacements needing to be either purchased or developed.

The third level of detail further breaks down predicted performance by the sex of calf, number of calves sold and weaning weight by cow parity. The sex proportion of calves is fixed to be half male - half female, however male calves are more likely to experience birthing difficulty and additional mortality at birth is levied against them. Weaning weight is adjusted following Beef Improvement Federation guidelines (2002). These guidelines assume young and very old cows will wean lighter calves while cows age 5 to 10 wean calves that express their full genetic potential through the maternal environment of the dam and their own growth potential. The number of female calves retained is dependent on the source of replacements in the herd.

The user has the option to constrain the simulation in several ways. For example, there is the option to hold the herd size constant, to hold the amount of feed consumed by the herd constant, to buy or raise replacements. The result of the various constraints may result in differential sire ranking, for instance, constraining the model to constant utilization of available feed resources versus stabilizing the number of cows impacts the herd size and replacements required. Allowing the herd size to shrink or grow based on ranch-wide feed consumption may lead to additional females sold or retained/purchased, dependent upon the growth potential and mega calories required versus the amount of feed available. If the model constrained to retain and raise replacements from within the herd, those females are removed from the pool of weaned calves available for sale. If replacements are purchased all weaned calves are sold and replacements are purchased at the user-defined price. The genetic merit of these replacements is assumed to be the average of the selected bull and the user defined cow herd regardless of source. The number of replacements necessary is dependent upon the predicted life span of the females. This life expectancy is the probability of being culled due to non-pregnancy, a function the calving rate is and stayability level. Additionally females from the four oldest user defined parities are forced to be culled at a rate of 25%, 50%, 75% and 100% respectively.

As true in real production, changes made to individual production components may interact with other production parameter aspects cascading into numerous effects. The ability to simulate these interactions is a benefit to this model. A simple example of this cascade of ramifications is birth weight. Birth weight influences calving ease which in itself is affected by herd age structure (i.e. proportion of first calf heifers) influencing calf survival and ultimately the number of weaned calves available for sale. Additionally birth weight influences the nutrient requirements of each individual via several pathways. Gestating cows requirements are affected by the weight of the calf in-utero and once born calves requirements of milk and feed are impacted. These feed requirements will ultimately affect herd size or feed purchases.

Threshold trait EPD used in simulation posed a unique challenge as they are not easily interpreted being expressed on the observed scale, they are not additive and biological interpretation is dependent upon level of production. Instead there must be a conversion to the underlying scale which requires trait variances and a normality assumption on the continuous underlying additive scale to make these EPD useful. Because these classes of EPD are reported as probability values, the percent favorable or unfavorable genetic response decreases as the phenotypic performance nears the extreme (0% or 100%). That is to say producers at a high level of performance in a threshold trait will benefit less from a one unit change in the EPD versus the same one unit increase in a low producing herd. Simulation is the only way to properly use these EPD as they depend on actual production level and are not equally additive across production schemes (Enns et al., 2005).

Comparison of Simulation Outputs:

Comparisons of model output will be made from three perspectives;

I. Varying the levels of production via the input parameters while holding the genetic merit constant.
II. Varying the levels of production via input parameters and varying genetic levels in single unit increments.
III. Varying the genetic levels of potential sires while holding user inputs/production level constant.

Each of the scenarios uses unique input parameters and sire merit and the results will be discussed separately.

Part I. Impacts of Input parameters:

The numbers of possible combinations of input parameters are nearly endless in an effort to represent differences in beef production by environmental conditions, marketing and management choices and external factors unique to individual herds. A constant set of user parameters was used for model inputs in part I and II of this discussion. These model inputs, summarized in table 4.1 are reflective of production in the western United States. Cow calf production in the Western Great Plains region was chosen because of familiarity and availability of historic data. Phenotypic weight inputs, birth, weaning, yearling and mature weight, were derived from the Red Angus association herd book. The average reproductive factors were obtained from the USDA National Health Monitoring System publication (USDA, 2008). Financial inputs were also derived assuming sale of livestock occurred in the western region. Historical USDA prices from Torrington, Wyoming livestock market were obtained from

Livestock Marketing Information Service and averaged over a 25yr time horizon (appendix 1 – 3). Prices included feeder calf price, heifer price and cull cow price. The USDA reports prices on both cutter and canner grades, for sake of simulation a 70/30 percent ratio of cutter to canner cull cows was used. Explicit historical prices of open yearling heifers were not available so average auction prices of 900 to 950 lbs. steers and heifers were averaged. Feed costs were also obtained from USDA data from 1990 to 2009 (appendix 4). Explicit average fixed production costs were not available over long periods of time, therefore applicable costs were averaged from the Kansas State enterprise budget figures (Dhuyvetter and Langemeier, 2010) for average, high and low cost producers and used as inputs.

The model uses 23 user inputs plus average genetics to simulate a base herd. This base herd is thought of as the current level of production the ranch is operating at. Changing any individual input will result in a different base herd. To investigate the ramifications of differing inputs without any changes to genetic level different base herds were created and output compared. User inputs were grouped according to type for simplification of discussion. The groups and traits varied within the groups were:

1. Growth scenario – Varying the average weights, birth, weaning, yearling and mature, above or below average two standard deviations.
2. Maternal scenario – Varying the average pregnancy rates of cows and heifers (separately), calf survival and calving assistance above or below average two standard deviations.
3. Financial scenario – Varying the feed costs, fixed costs, and calf, heifer and salvage cow prices above or below average two standard deviations.

The averages used to create these groups were considered the baseline for which comparisons are made. Within each of the three production factor groups, production was simulated at high and low levels of efficiency, 2 phenotypic standard deviations above or below the mean. All other production factors were held at baseline levels. Seven simulations were run using these inputs, 1 baseline and each high-low combination by three production levels.

From these results the greatest impact on overall profitability is achieved when the financial factors of the model are increased by two standard deviations above the mean, followed by increasing the growth inputs used by the model (table 4.2). The maternal scenario did not return net difference in the same magnitude, possibly due to the percentage nature of the phenotypes and low standard deviations. The model does perform logically, when production levels are increased in any category net revenue also increases and conversely for decreased production levels.

There are no differences in number of calves sold in either the growth or financial scenarios obviously because the heifer and cow calving rates are held constant. Similarly in these two scenarios there are no additional replacements required or sold because of stayability is held constant. In the growth scenario the differences in the weight of calves sold has the greatest impact on overall profitability. In the maternal scenario the difference in stayability changes the number of female calves sold or retained, greatly impacting revenue. Under differing pricing scenarios the greater sale prices with low feed prices lead to higher system wide profitability.

Table 4.1. Model parameters used in the comparison of three production trait groups, growth, maternal and financial, high versus low scenarios.

	Baseline averages	Growth Potential (high / low)[a]	Maternal Ability (high / low)[a]	Financial Factors (high / low)[a]
Heifer Calving Rate	83%[b]		95% / 71%	
Mixed Age Calving Rate	92%[b]		96% / 88%	
Mature weight	1274.4[c]	1396 / 992		
Calf Survival Rate	97%[b]		98% / 96%	
Yearling Weight	924.8[c]	1038 / 781		
Weaning Weight	579.7[c]	674 / 486		
Birth Weight	81.8[c]	93 / 70.6		
Heifer Calving Difficulty	11.6%[b]		8.8% / 15.2%	
Incremental Cow Costs	$25.78[d]			$26.26 / $27.17
Heifer Price	$87.76[d]			$123.22 / $52.30
Cow Price	$44.10[d]			$58.24 / $29.96
Calf Price	$100.70[d]			$139.34 / $62.06
Feed Cost	$93.78[d]			$56.45 / $131.04
Production inputs held constant across all simulations				
Herd Size		1000		
Constant Input		Cow		
Breeding System		Maternal		
Replacement Constraint		Bred		
Cows Per Bull		1		
Maximum Cow Age		12		
Capital Value of Heifers		1000		
Capital Value of Cows		800		
Capital Value of Bulls		2000		
Cost of Replacement Heifers		800		

[a] - High/Low groups represent +/- 2 standard deviation from the baseline parameter
[b] – USDA National Health Monitoring System publication (USDA, 2008)
[c] – Breed average of 2009 Red Angus association of America database
[d] – Dhuyvetter and Langemeier, 2010
Parameters left blank under any high/low group use baseline parameters

Table 4.2. Deviations from base herd of varying input parameters of DSS model assuming a 1,000 cow herd.

		Income	Expenses	Net/Bull	Males Sold	Females Sold	Replacements Retained	Avg WWT
Growth Potential	high	100,854.93	0	100.85	0	0	0	117
	low	-151,280.50	0	-151.28	0	0	0	-182
Maternal Ability	high	16,732.40	-1,104.11	17.84	6.65	52.50	-46.27	2
	low	-12,266.65	1,683.19	-13.95	-6.79	-70.84	64.53	-2
Financial Factors	high	187,226.52	519.29	186.71	0	0	0	0
	low	-187,226.52	1,503.78	-188.73	0	0	0	0

Part II: Relative Economic Values

Under differing production parameters the value and rank of each traits relative economic value (REV) may change relative to the current level of production and economic situation. Therefore discussion within this section is limited to a single environment production scenario. For purpose of examining the economic effects of changing individual traits genetically within different production scenarios, REV were simulated using the previously described input scenarios (table 4.1).

A relative economic value is defined as the value (in dollars) of a one unit increase in an individual traits' EPD while genetic merit in all other traits are held constant. The REV of each trait is calculated by simulating future returns from set input parameters only changing the trait by one unit while holding all others at zero. The resulting value of hypothetical genetic change is attributed to the traits effect over the entire system. For example a one unit increase in herd average weaning weight will affect the feed requirements of the herd due to higher growth potential but will also increase total weaning weight sold by the system. Of course, the overall economic impact depends on the market conditions at the time of sale as well as feed resources available in the system.

Simulation outputs of total system cost and income for each of the nine REV EPD are summarized in table 4.3 for each production circumstance. Among the seven simulations stayability or maintenance energy have the greatest economic impact, increases in income ranged from 595.88 to $1,322.74 for a one percent greater stayability and one unit change in maintenance energy increased costs ranging from $1,707.13 to 735.40. These two traits rank first or second for all simulations, displaying the importance of the cow herd costs over the revenue. As discussed previously increasing stayability shifts the herd age structure and decreases need for replacements. Similarly decreasing maintenance energy requirements of mature cows decreases the need for additional feed, the most costly variable cost in cow calf production. Of the remaining six EPD their REV rank depends on the production circumstance. The net value, net income – net costs, of each EPD are graphically represented for each production circumstance in figures 4.1, 4.2 and 4.3. All REV EPD were simulated at a plus one for interpretation, although traits such as BWT and ME lower values are more desirable.

Under certain specific scenarios a trait can be beneficial in either positive or negative directions. For example a one unit increase in heifer pregnancy will result in fewer replacements being required, but a one unit decrease will result in additional open heifers to sell as yearlings. This is the case in figure 4.3, where in the high financial case the value of open heifers outweighed the values of replacements and increasing HPG actually became a cost. Weaning weight maternal is another example of this phenomenon. Under the low financial scenario in figure 4.3, where feed prices are high and calf prices are low it is detrimental to increase WWM due to the increased feed costs due to lactation outweigh the increase in WWT.

Table 4.3. Relative economic values of income and cost sources separately, of each EPD used in the simulation for varying production parameters.

	Baseline		High Growth		Low Growth		High Maternal		Low Maternal		High Financial		Low Financial	
	Income	Cost	Income	Cost	Income	Cost	Income	Cost	Income	Cost	Income	Cost	Income	Cost
BWT	0	92.18	0	74.09	0	117.83	0	92.63	0	91.71	0	55.51	0	128.86
WWT	756.70	205.41	756.70	218.14	756.7	186.40	817.07	212.36	678.46	196.80	1047.06	123.70	466.35	287.15
YWT	20.470	75.86	20.47	80.86	20.47	75.37	4.96	60.10	45.85	97.39	28.74	45.68	12.2	106.04
Milk	756.70	534.84	756.70	547.58	756.7	515.84	817.07	539.24	678.46	528.79	1047.06	322.08	466.35	747.66
CED	28.94	-13.24	34.95	-13.24	19.57	-13.24	19.57	-8.97	39.60	-18.06	40.05	-13.24	17.84	-13.24
HPG	-417.88	-507.92	-536.89	-622.72	-369.77	-395.68	-120.21	-146.80	-873.79	-1056.73	-601.21	-322.67	-234.55	-696.14
CEM	57.36	-26.24	69.26	-26.24	38.8	-26.24	38.76	-17.77	78.54	-35.81	79.37	-26.24	35.35	-26.24
STAY	970.46	-538.49	1146.27	-691.26	694.24	-378.35	595.88	-247.97	1196.71	-930.62	1322.74	-332.88	618.17	-745.38
ME	6.70	1221.20	6.70	1217.38	6.70	1225.55	1.62	1178.43	15.01	1281.08	9.41	735.40	4.00	1707.13

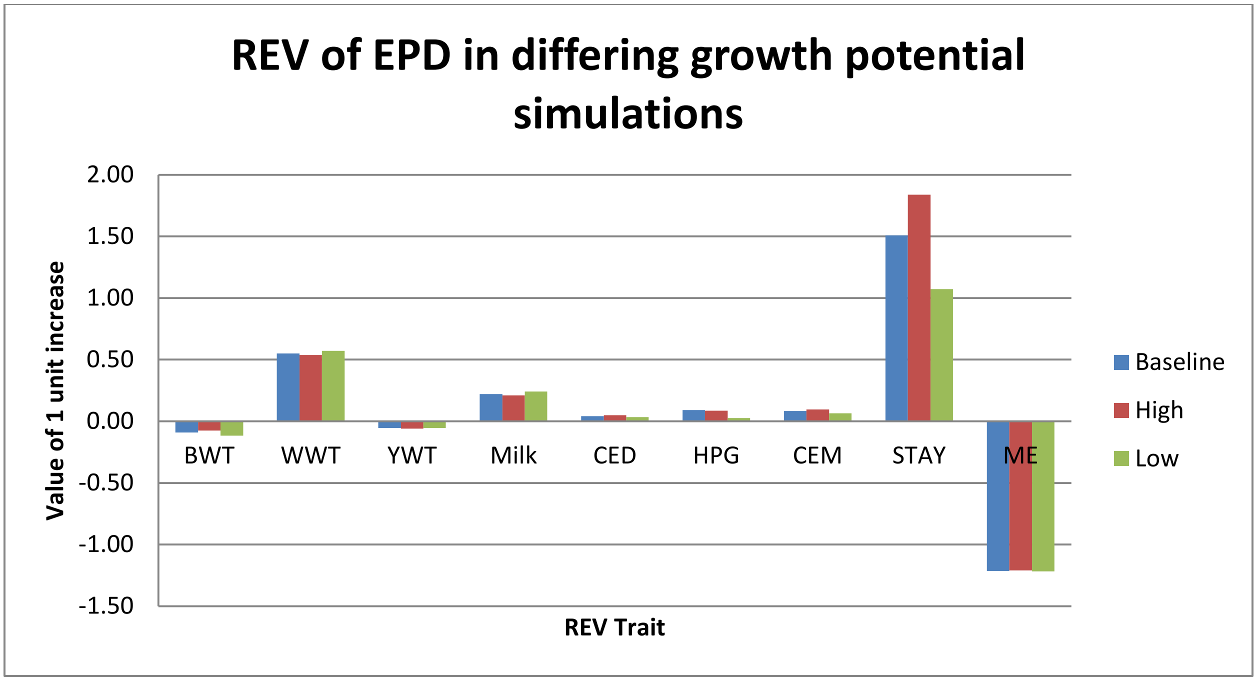

Figure 4.1. Relative economic values of EPD used in simulation of baseline production parameter versus high and low growth potential scenarios (+/- 2 std dev)

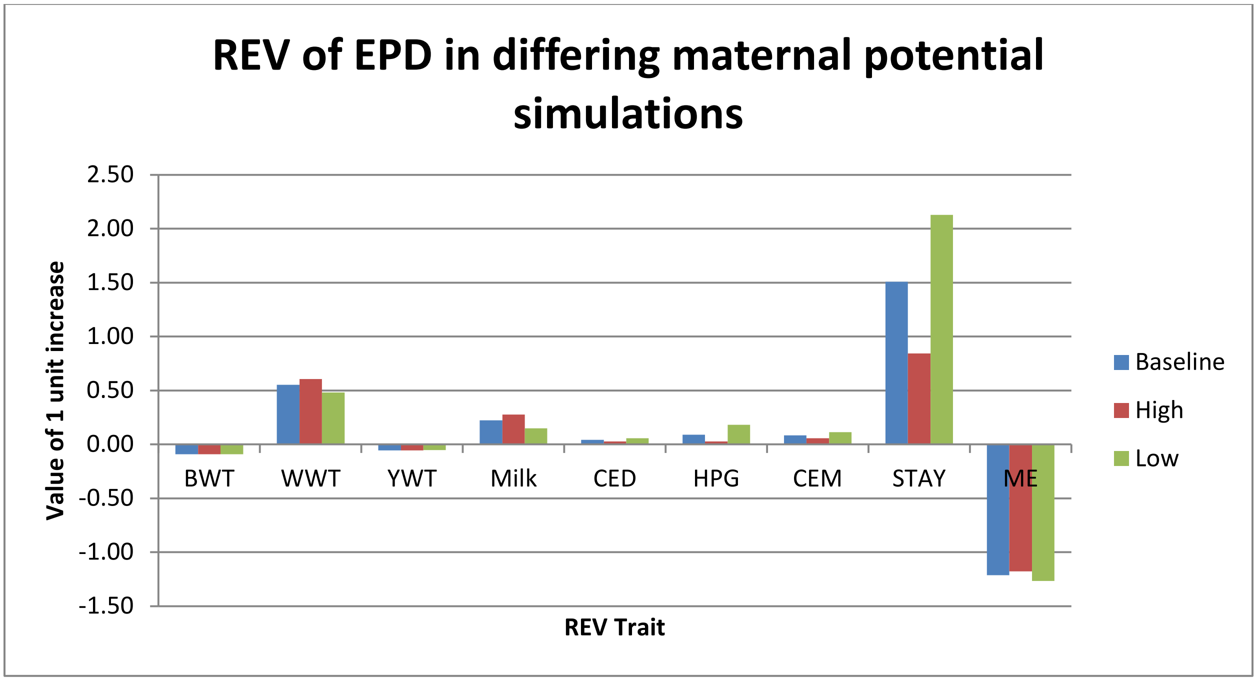

Figure 4.2. Relative economic values of EPD used in simulation of baseline production parameter versus parameters of high and low maternal characteristics scenarios (+/- 2 std dev)

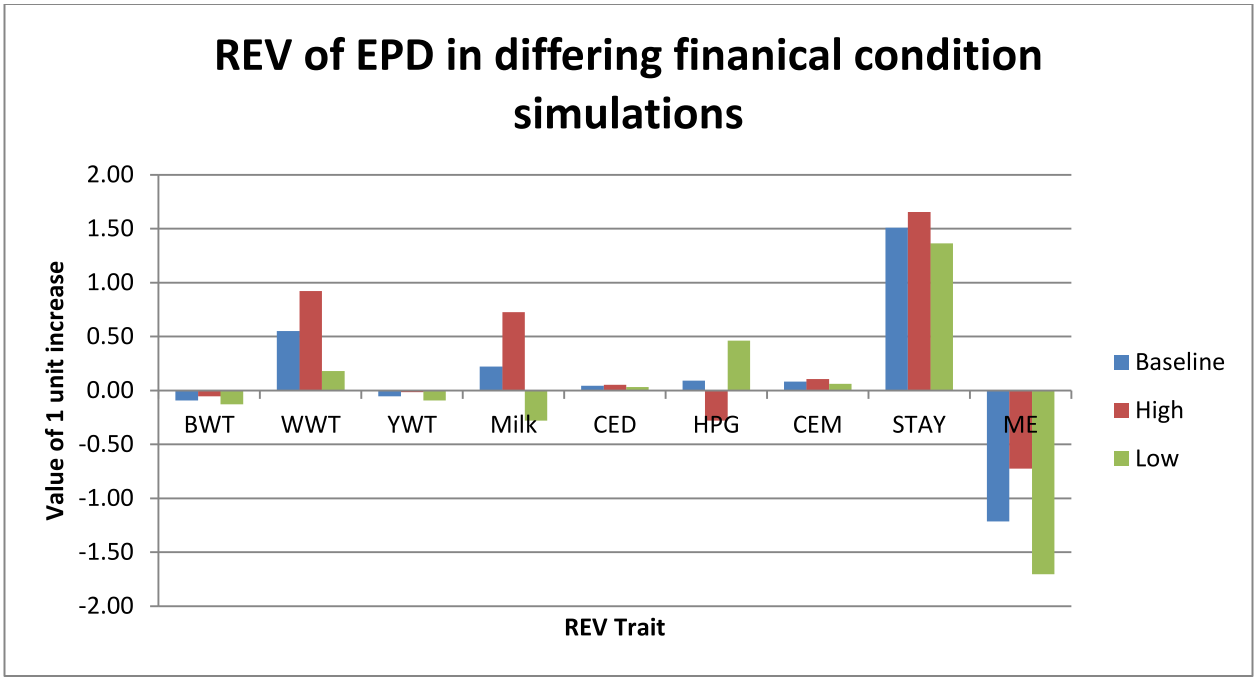

Figure 4.3. Relative economic values of EPD used in simulation of baseline production parameter versus high and low financial factors (+/- 2 std dev)

Part III. Impacts of Sire Genetic Merit:

Using average EPD of proven sires from 2009 Red Angus Association of America (RAAA) genetic evaluation three reference test bulls were made to compare model effects at differing genetic levels. Summary of these three fictitious bulls are shown in table 4.4, the above average and below average EPD suites were made 3 standard deviations from active sire breed average. Using these EPD in conjunction with default herd parameters (Table 4.5) a simulation was performed assuming these three EPD sets each represented an individual bull available for use in the breeding herd. Hereafter, each of the suites will be references as a bull, high, average and low. The results from the use of these three “bulls” are discussed below. All comparisons are made relative to the deviation from the base herd performance, i.e. if no genetic change was made the expected deviation between the two outputs would be zero. Under this base herd scenario the user input EPD (base) are assumed to be the fixed level of future production. The simulated herds subsequently become the average of the base plus the bull EPD.

Table 4.4: EPD suites of Red Angus 2009 proven sires (average) and three standard deviations above and below average used to compare simulation outputs.

	CED	BW	WW	YW	MILK	ME	HPG	CEM	STAY
Base	4	0.5	26	44	13	3	8	3	8
Below Avg.	3	1.5	25	48	13	8	7	1	7
Average	6	-0.2	32	60	17	4	9	4	9
Above Avg.	9	-1.9	39	72	21	0	11	7	11

Table 4.5: Default input parameters used in simulation of below average, average and above average bulls EPD results.

	Default Value
Herd Size	1000
Heifer Calving Rate	95%
Mixed Age Calving Rate	90%
Mature weight	1200
Calf Survival Rate	95%
Yearling Weight	775
Weaning Weight	500
Birth Weight	85
Heifer Calving Difficulty	22%
Constant Input	Cows
Breeding System	Maternal
Replacements	Bred
Cows Per Bull	30
Maximum Cow Age	12
Incremental Cow Costs	$25
Capital Value of Heifers	$1000
Capital Value of Cows	$800
Capital Value of Bulls	$2000
Heifer Price	$55
Cow Price	$48
Calf Price	$100
Cost of Replacement Heifers	0

The general output of the simulation is presented in table 4.6. As expected the greater the genetic merit, relative to base herd genetics, the greater the returns. Given these bull options, the factor with the largest effect within the system is the differences in productive life of females. The six fewer replacements retained in the above average herd (Table 4.6) increases income from the sale of those females but also indicates a shift in the age structure to older females of the entire herd.

Correspondingly the impact age structure has on the simulated system is the primary driver of the changes in profitability. The shift in age structure is shown below in figure 4.4. The above average EPD suite results in a greater number of cows in all age classes greater the 5, while the below average EPD suite results in fewer number of mature cows in all age classes greater than 5. Herd stayability is calculated from the proportion of 2yr old females to 6yr old females with the EPD influencing the underlying scale adjusting up or down the number of females in each age class. The non-linear aspect of this threshold trait is evident in the differences among these 3 test bulls. While the differences in stayability EPD between the bulls is linear, +7, +9 and +11, below average, average and above average respectively, the resulting simulated age structures are not given the base herd stayability (65.61%). The resulting phenotypic stayability of the three test bulls are: 64.8%, 66.4%, 68% and resulting mature calving rates in 89.7%, 90.3% and 90.8% for low, average and high respectively. The differences between the test bulls was 2% for stayability EPD but only resulted in 1.6% phenotypic differences.

Table 4.6: Summary of simulation outputs using Red Angus 2009 proven sires as average compared to three standard deviations above and below the mean EPD suites. Mated to default herd parameters.

	Herd Size	Income	Expenses	Net/Bull	Males Sold	Females Sold	Replacements Retained
Base	1000	$ 394,506.30	$ 32,366.64	$ 362.14	471	291	182
Below Average	1000	$ 392,381.87	$ 38,044.58	$ 354.34	471	289	184
Average	1000	$ 403,318.87	$ 36,184.64	$ 367.13	472	294	180
Above Average	1000	$ 414,214.70	$ 34,440.04	$ 379.77	472	298	176

This non-linear affect is also evident in the number of replacements retained per cow age class shown in figure 4.5. The number of replacements necessary to maintain the fixed herd size is derived from mandatory culling of the three oldest parities, 25/50/100 percent, and culling of non-pregnant females from all parities. With increases in heifer pregnancy rate and mixed age pregnancy rate the number of replacements necessary decreases.

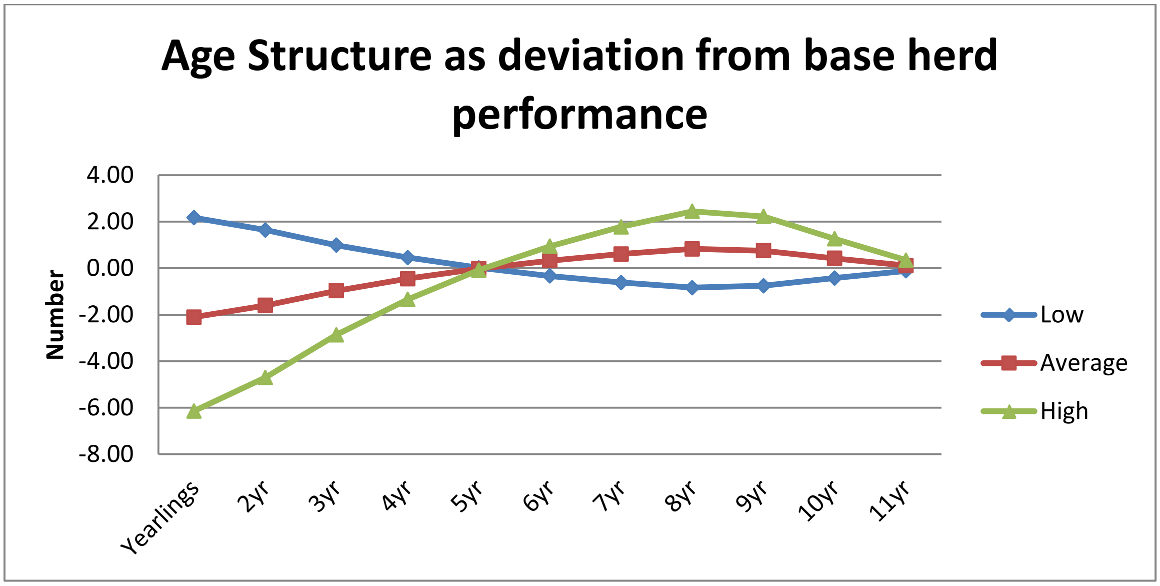

Figure 4.4. Simulated difference, compared to base herd, among above average, average and below average EPD suites of the number of females per parity.

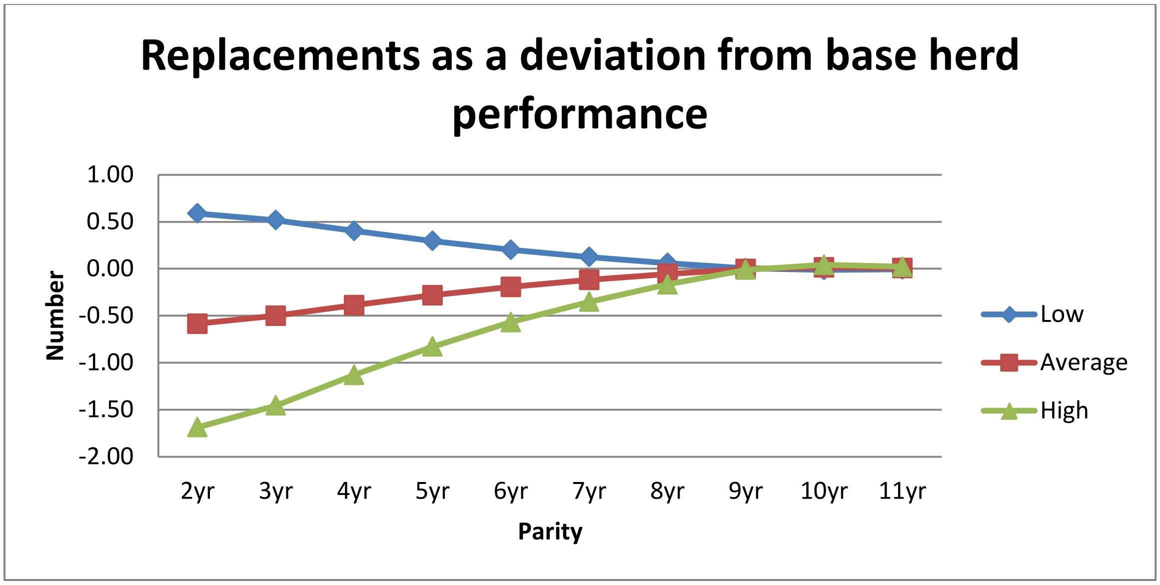

Figure 4.5. Simulated differences, compared to base herd, among above average, average and below average EPD suites of the number of female replacements retained per cow age class.

The primary revenue of the system is derived from the sale (per pound) of weaned calves followed with revenues also generated from salvage value of open and old age culled cows as well as open yearling heifers. Figure 4.6 displays the likeness between the change in age structure and the number of calves sold by parity. The shift toward a greater number of mixed age cows allows full genetic potential expression in the calves and increases total pounds weaned and in turn revenue. Not only does the above average test bull have an advantage in stayability leading to the increased number of female calves sold, increases in heifer pregnancy rate also lead to fewer open heifers being sold at salvage rates. Numerical differences in heifer pregnancy rate are not as graphically dramatic due to the base herds high default value of 95%. As previously stated high producing herds benefit less from increases in threshold traits. Comparing figure 4.4 to 4.6 shows a greater decrease in the number of early parity females compared to the difference in number of calves sold. In the case of the above average EPD suite there is a decrease of 5 two year old females compared to the decrease of only 2 weaned calves sold, with fewer females producing more efficiently.

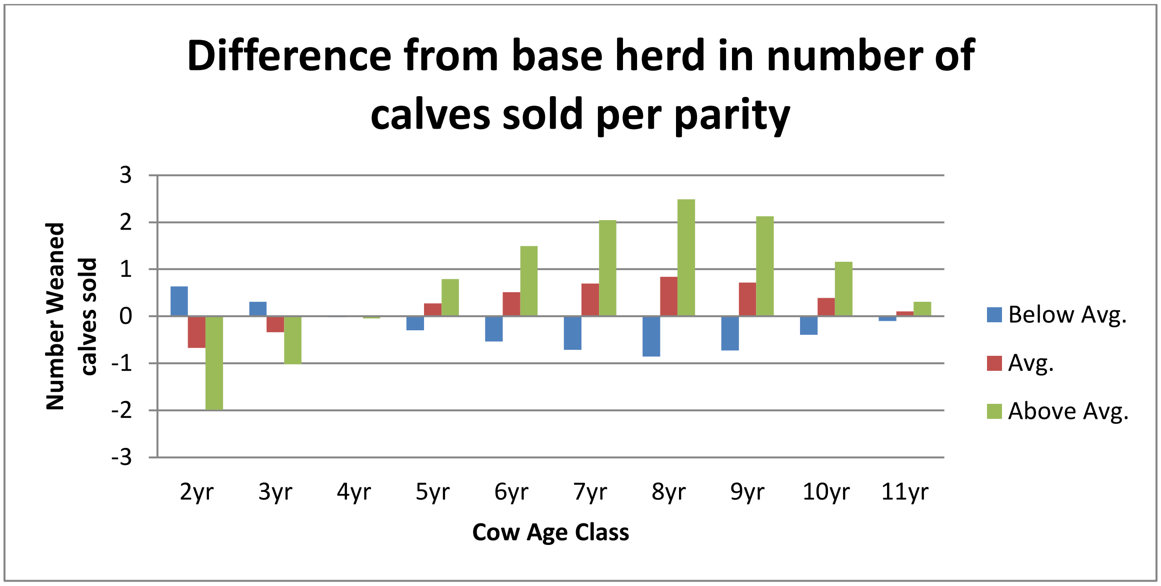

Figure 4.6. Simulated differences, compared to the base herd, among above average, average and below average EPD suites of the number of calves sold per cow age class

Extending the differences in the number of calves sold to the value of calves sold, figure 4.7, shows the greater advantage the above average EPD suite has compared to others. Not only are there additional calves from later parity females to be sold, these calves are heavier and therefore worth more. The average weaning weight for each of the EPD suites are 489, 499 and 510 pounds for below average, average and above average respectively compared to 490 pounds in the base herd. The below average test bull exhibits negative returns in 7 of the 10 cow age classes compared to the base. This is because the low EPD suite results in the fewest number of calves available to sell due to decreased female stayability and also the lowest average weaning weights of the three simulated suites.

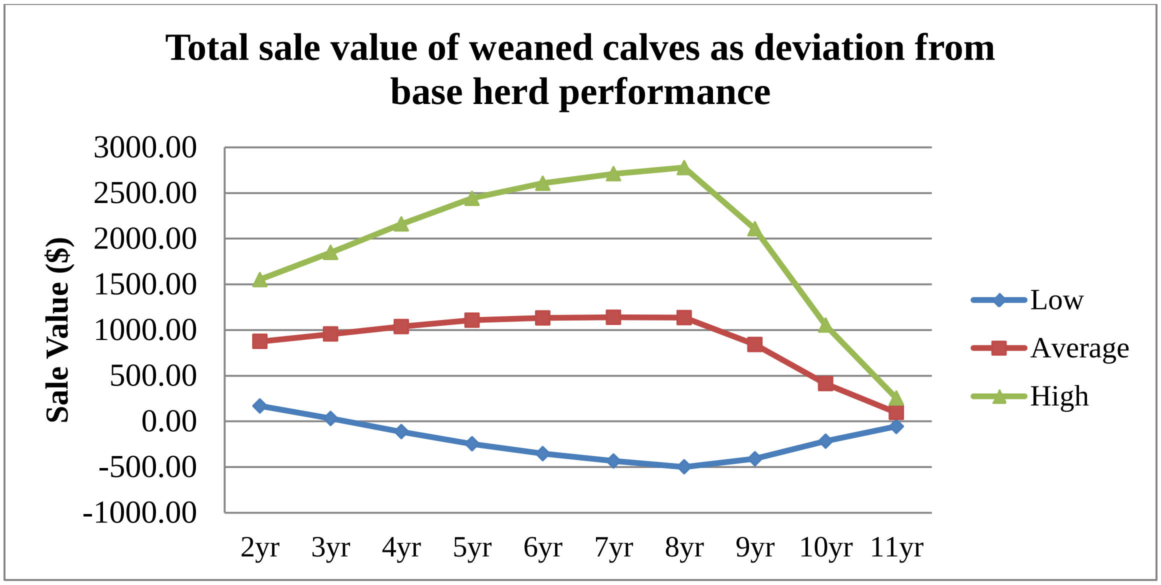

Figure 4.7. Simulated differences, compared to the base herd, among above average, average and below average EPD suites of the total sale value of weaned calves per cow age class

Breaking the revenue stream of the three test bulls into its components, costs and revenues, by age class of animal, additional details of what effects the differing genetic potentials have on profitability can be evaluated. Table 4.7 details the cost and revenue deviations from the base herd three animal groups, all calves, 2 year olds and all mixed age cows, for each of the three EPD suites. The whole herd or overall net income difference among the three suites shows that for increasing the bulls merit by 3 standard deviations, below average to average or average to above average, results in an increase of $12,796.95 and $12,640.42 increase over the 1,000 cows.

In the revenue portion of the table the difference in calves' monetary value is driven by the actual amount of weight sold and the number of calves available to sell. The revenue from 2 year old females is lower in the average and above average scenarios because there are fewer open females being sold from this age class compared to the below average case. In this case the negative revenue is a benefit because it shows females are remaining productive in the herd and not being replaced.

In the cost side of the table, the results follow the same trend as the revenue, the below average EPD suite under performs both the other EPD suite. The increased cost of calves in the below average herd shows the effect of calving ease in the model. As the probability of unassisted births goes down the costs go up. Within the simulation there is an assumed veterinarian charge of twenty five dollar levied to each assisted birth. Conversely the increased costs for mixed age cows under all EPD suite scenarios show the increase in cow growth potential and feed requirements. Although the above average EPD suite does not increase maintenance energy requirements, ME EPD 0, the increased number of mature cows results in additional feed consumption. At the opposite end of the spectrum the below average EPD suite increases maintenance requirements, ME EPD +8, resulting in the greatest increase in inputs required to maintain the cow herd.

Factors effecting the total feed requirements of the herd include all growth traits: birth weight, weaning weight, yearling weight and mature weight. Each has a direct additive effect on the simulated growth curve, which in turn determines the mega-calories of energy necessary for maintenance of the herd and reproduction. As previously stated as weaning weight, yearling weight and mature weight increase so does the value of all animals sold. However this is a trade off since is the system is charged additional energy requirements (feed) to support these heavier weights. Under this simulation criteria the size of the cow herd was fixed, thus any additional mega-calorie requirements above the base herd were assumed purchased to feed the herd. Figure 4.8 illustrates the actual amount of change, in mega-calories, each of the EPD suites added to the simulated herd. Note the slope differences in figure 4.8 from the yearling parity to six years, in this particular unique case the above average EPD suite has the highest YWT EPD yet the lowest ME EPD. Although this reflects an ideal bull, high for growth - low for maintenance requirements, it also reflects the simplification of the growth curve. The YWT EPD additive effect increases the simulated yearling weight of replacement females while the MEM EPD, which has a mature weight partition, decreases the mature size of cows 6yr and older. The second through fifth year average weights are a linear function of mature weight with two mid points of 60% and 80% of mature weight reached at 730 days and 1,095 days respectively.

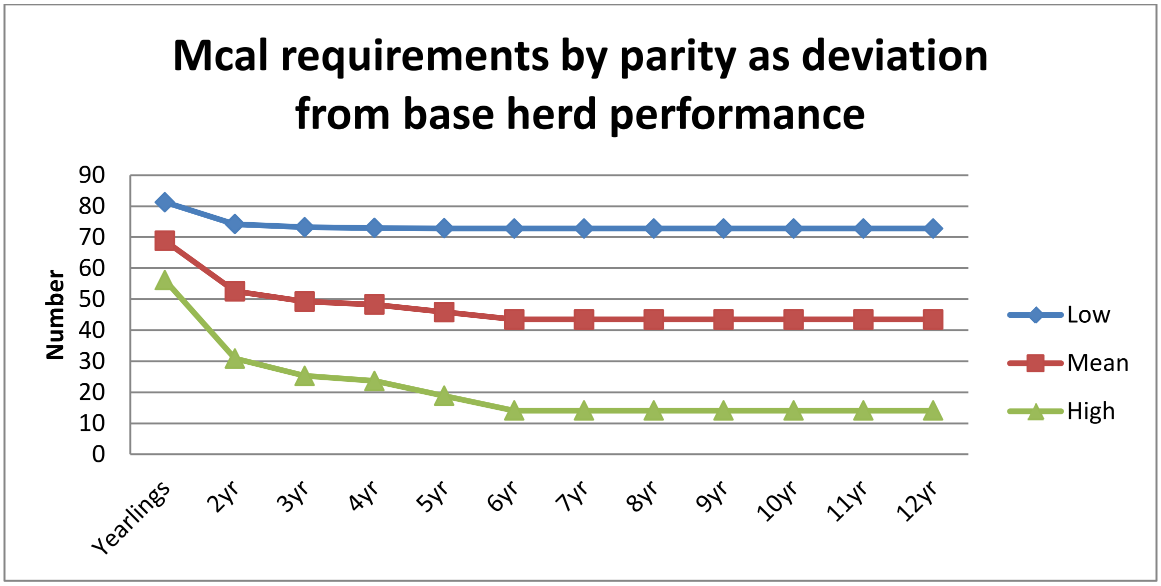

Figure 4.8. Simulated differences, relative to the base herd, among above average, average and below average EPD suites of the mega-calorie required per parity of cows

Table 4.7. Breakdown of simulated revenue and cost sources for above average, average and below average EPD suites, relative to the base herd for all calves, 2 year old females and all mixed age female groups

	Income sources			Cost sources			Net Income
Age Class	Calves	2yr	Mixed Age	Calves	2yr	Mixed Age	
Below Avg.	- $ 2,128.00	$ 284.36	- $ 280.72	$ 135.88	$ 67.77	$ 5,474.29	- $ 7,802.37
Avg.	$ 8,729.71	- $ 195.72	$ 278.59	- $ 103.01	- $ 65.82	$ 3,986.82	$ 4,994.58
Above Avg.	$ 19,512.68	- $ 633.30	$ 829.03	- $ 308.14	- $ 191.83	$ 2,573.37	$ 17,635.00

Extending from the individual animals simulated change in energy requirement, total herd requirements are shown in figure 4.9. This figure shows an increase in overall requirements of the cow age classes thus requiring additional feed resources. On a whole ranch view the minor increases in individual feed requirements shown in figure 4.8 are extrapolated to account for differences in age structure, closely mirroring the figure 4.4. The net change in feed requirements for the three EPD suites were; 395,759, 283,212, and 176,231 mega-calories per year for the low, average, and high EPD suites respectively. These increases are charged at the user defined rate, in this case $75 per ton of feed, resulting in additional feed costs of $5,515, $3,947, and $2,456 for below, average, and above EPD suites respectively.

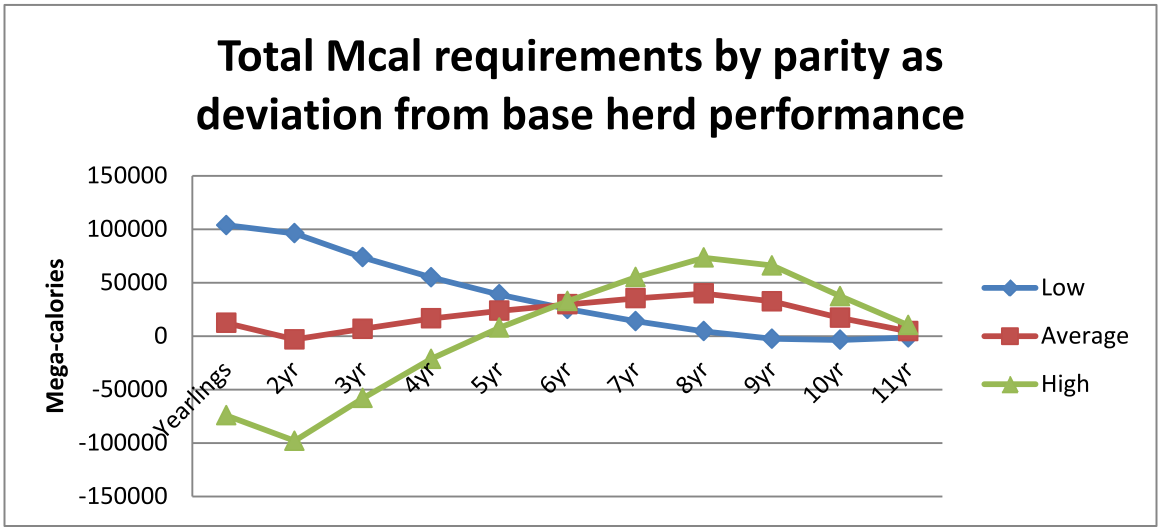

Figure 4.9. Total mega-calorie requirements per cow age class relative to the base herd, among above average, average and below average EPD suites

If the user inputs were changed to fix the amount of feed available, feed constant option, and the model re-run the overall number of cows is adjusted up or down to use only the available feed. This restraint would lead to decreasing the herd size by 11, 8 and 5 cows for below average, average and above average EPD suites respectively. The shape of the age structure curve of this case looks very similar to figure 4.4, where the herd size was held constant, only slightly lower in magnitude over all age classes. In fact, all of the summary graphs previously presented constraining number of cows match the feed constant constraint, only differing in the number of cows/calves in each age class to equalize overall herd consumption.

Across breed simulation usage:

This simulation model was developed under the assumption across breed EPD would be available from a single evaluation in the future. In the interim cross bred hybrid vigor is not accounted for in anyway. The model uses EPD from any breed as equivalent. If the user was to define a base herd of breed A and choose a bull from breed B the model assumes no performance differences in the resulting output. That is to say the simulation runs as if the two were the same and does not adjust performance outcomes for heterotic effects.

If across breed EPD do not become available an intermediate alternative approach to adjusting for breed effect would be to add routines which make use of the EPD breed adjustment factors published by the Beef Improvement Federation. Currently this option would only be useful for weight traits, as the across breed adjustment do not include threshold traits. As future research is completed for traits which don't currently have breed adjustments this maybe the best alternative to account for breed differences. Although this method would not account for hybrid vigor/heterosis of daughters from the simulated matings, it would account for numerical differences of the EPD used.

Complete EPD suites

In addition to a lack of a breed adjustment factors for some traits, some breeds do not currently have all of the required EPD for the simulation to fully account for genetic differences between animals. In cases where EPD are not available the simulation model assumes no genetic change in future generations in that trait. For example, in a breed which does not have maintenance energy EPD cows are assumed to mature to the exact weight as parameterized by the user and genetic change in other traits will not influence mature weight. In this case the YWT EPD may be indicator of positive or negative mature weight, due to the high genetic correlation between the two traits, but the model will not accept this as a proxy in its current structure. As of this publication the only breed which has all the necessary EPD to completely parameterize the simulation is the Red Angus Association of America.

Risk and Accuracy

Accuracy differences must be taken into account during any selection decision involving comparison of animals with differing accuracy. This simulation model does not consider accuracy values associated with EPD. Well proven sires can be directly compared to young sires with little to no accuracy. A high accuracy sire will have a much narrower confidence range around an EPD while an unproven sire has a much wider confidence range. Directly comparing simulation results between two such sires may lead to unproven sires appearing better or worse than they may actually be. As demonstrated in this discussion changes in any EPD cascade though the entire production system changing the output prediction. Obviously the more accurate the EPD used in simulation the more accurate the simulation results will be. It would be advised to only compare sires of similar accuracy levels.

Discounted gene flow

At the present time discounting of future returns to a net present value is not attempted with this simulation. The interest parameter entered by the user does not affect the model in any way, it is present for the potential of inclusion of discounting in the future only. If it were to be integrated into the simulation it would require several additional user inputs, for example the number of years a bull is used and selection of multiple bull "types" for future mating. Currently the model simulates a herd of daughters whose genetic merit is ½ Bull EPD + ½ Base Cow herd EPD. If accounting for the time value of money were desired along with accounting for the age of trait expression a much more explicate future genetic potential would need to be included. As an example, the milk EPD is a prediction of potential weaning weight of sire's daughters. Being a trait of a sire's daughters, milk is not expressed until more than three years after the initial breeding occurs. To properly account for genetic merit in the short term, less than 20 years in the future, the model would need to simulate individual cow age by genetic merit classes.

The framework of this model could be adapted to simulate a herd on an annual basis with several different cow herd genetic potentials occurring within the herd at any one time. It is doubtful many users of this model would be able to select the genetic level of a bull they may use 20 years in the future, however the genetic trend of the breed of sires may be used as a proxy for future EPD merit. Genetic merit of daughters for traits with direct effects on progeny, BWT, WWT, YWT, and CED, are fairly straight forward. Table 4.8 illustrates how these traits would lead to a herd with several genetic merit levels occurring simultaneously. Some assumptions, particularity of the traits with longer lag times to expression (Milk, HPG, CEM, Stay, and MEM) would still be required. As an example, the time for expression of mature weight genetic differences would lag six years behind sire use. Similarly HPG and CEM would be two years behind changes in sire genetics.

To simulate the herd age structure, phenotypic stayability of daughters with different genetic potentials would be combined into a weighted average stayability of the herd for a single year, with that profile changing over time as the females mature. The requirements of simulating progeny from individual age classes with differing genetic potential would increase the computational complexity from tracking a single calf crop to tracking calf groups by age of dam up to the maximum cow age. To address this a user defined number of years a bull is used would need to be incorporated. Restricting the parameters such that a bull must be used for a minimum of three years reduces the number of potential genetics levels within the herd at any one time to five. To accomplish this model addition in an effective manner would require a complete rework in the logic and computation routines currently employed.

Table 4.8. Cow herd genetic potential, of direct effect traits, over time assuming a bull is used for 4 breeding seasons and replacements are developed from within the herd from the youngest parity females

		Year														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Cow Parity	1	O	A	A	A	A	B	B	B	B	C	C	C	C	D	D
	2	O	O	A	A	A	A	B	B	B	B	C	C	C	C	D
	3	O	O	O	A	A	A	A	B	B	B	B	C	C	C	C
	4	O	O	O	O	A	A	A	A	B	B	B	B	C	C	C
	5	O	O	O	O	O	A	A	A	A	B	B	B	B	C	C
	6	O	O	O	O	O	O	A	A	A	A	B	B	B	B	C
	7	O	O	O	O	O	O	O	A	A	A	A	B	B	B	B
	8	O	O	O	O	O	O	O	O	A	A	A	A	B	B	B
	9	O	O	O	O	O	O	O	O	O	A	A	A	A	B	B
	10	O	O	O	O	O	O	O	O	O	O	A	A	A	A	B
	11	O	O	O	O	O	O	O	O	O	O	O	A	A	A	A
	12	O	O	O	O	O	O	O	O	O	O	O	O	A	A	A

O = Original base herd cow genetic
A = Daughters of bull 1 bred to O cows
B = Daughters of bull 2 bred to A cows
C = Daughters of bull 3 bred to B cows
D = Daughters of bull 4 bred to C cows

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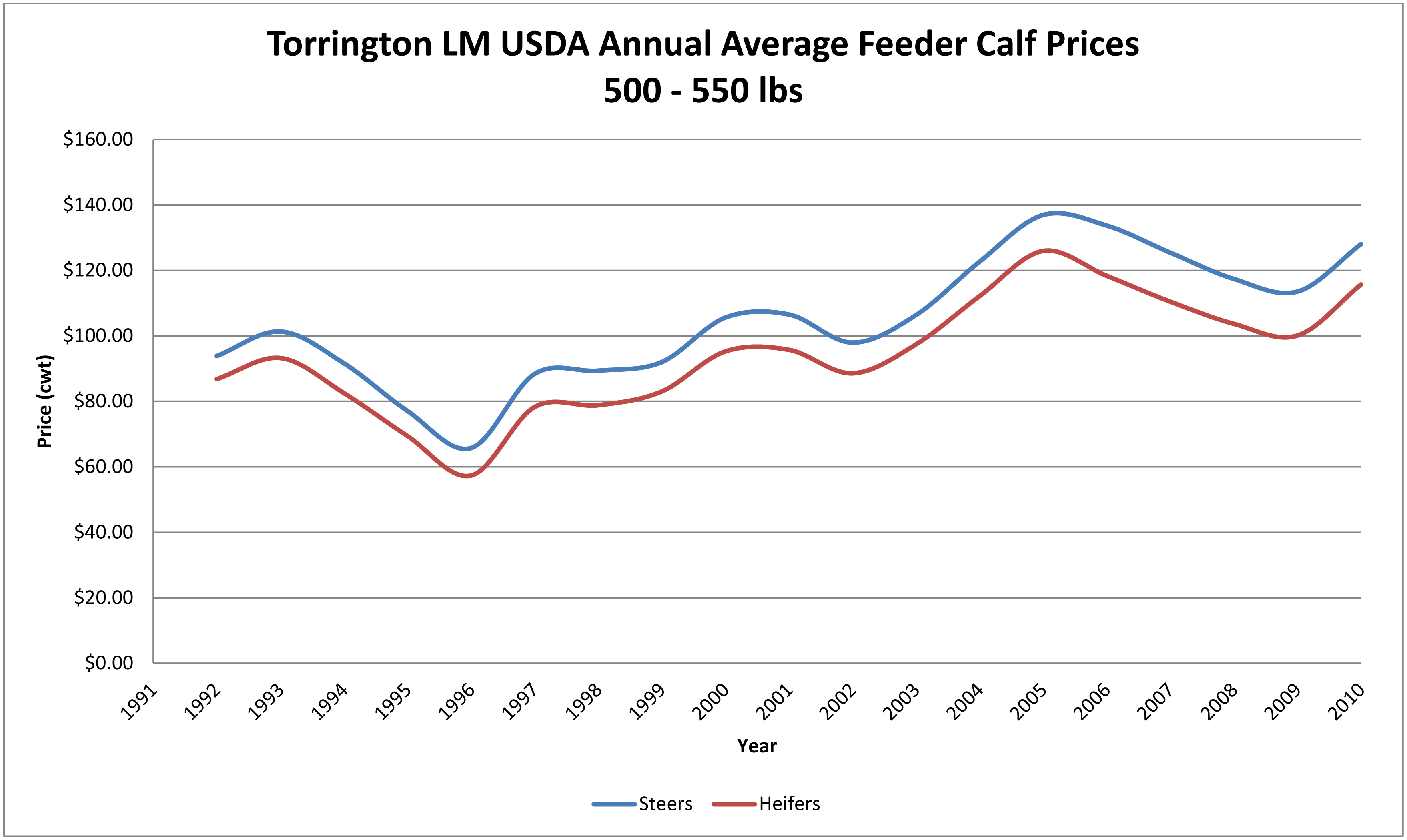
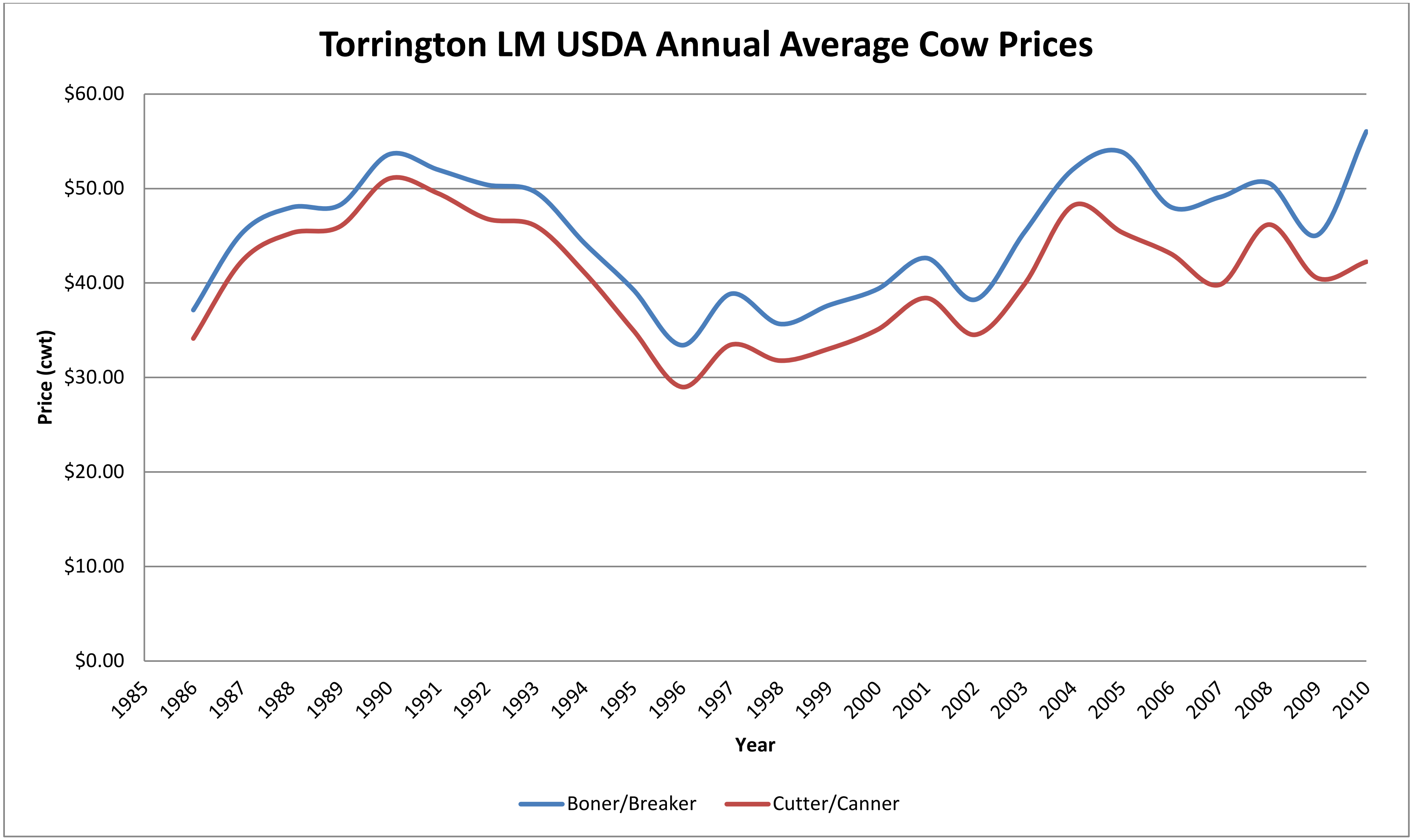
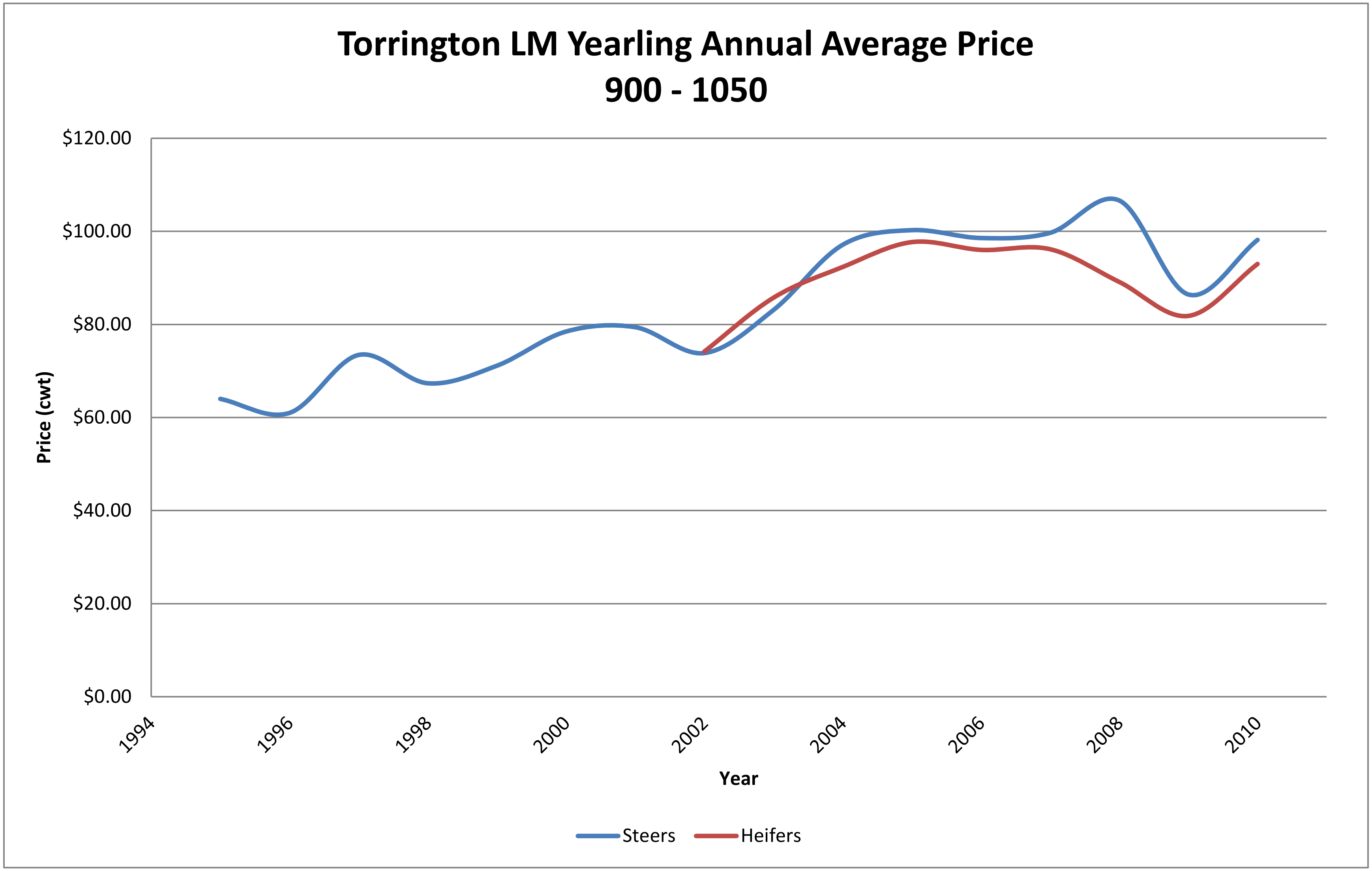
Appendix 1. Ten year average of feeder calf prices received at Torrington Livestock Market, WY.



Appendix 2. Twenty five year average of cull cow prices, boner and cutter grades, received at Torrington Livestock Market, WY.



Appendix 3. Sixteen year average of yearling feeder steer and yearling heifer prices received at Torrington Livestock Market, WY.



Appendix 4. Twenty year average hay prices reported by USDA.