Life cycle evaluation of five biological types of beef cattle in a range production system
by Kathleen Jeanne Christensen Davis

A thesis submitted in partial fulfillment of the requirements for the degree Master of Science in Animal Science
Montana State University

Abstract:
Data collected on five dam breedtypes, Hereford (HH) , 50% Angus-50% Hereford (AH), 25% Simmental-75% Hereford (1S3H), 50% Simmental-50% Hereford (SH), and 75% Simmental-25% Hereford (3S1H), were used to develop a life-cycle, stochastic model of cattle production. Yearlings were bred to a single Red Poll sire with subsequent matings to either Charolais or Tarentaise sires. Model inputs were cow weights at four times during the production year, calf birth and weaning weights, and pregnancy, dystocia and calf survival rates. Expenses included feed costs (supplementation, pasture rent and hay costs) , and non-feed costs (replacements, bulls, veterinary costs, labor, marketing and interest). Returns were based on the sale of calves and cull cows. Five replications were simulated for each dam breedtype x sire breed combination, with 60 heifers started for each system. Measures of system performance included number of matings, calves weaned per cow exposed, calf weight weaned per cow exposed, DM and Meal of ME consumed per kg of calf weight and total weight sold, input cost per kg of steer equivalent weight sold, cost of production, and net returns. Data were analyzed using two-way analysis of variance. Sire breed effects and the interaction were not generally significant while dam breedtype effects were highly significant for traits. Economic efficiency and net returns were closely related to the number and weight of calves sold, but not to measures of energetic efficiency or productivity defined as total weight sold per cow exposed when comparing dam breedtypes. The SH and AH dams were consistently more profitable, though they were least energetically efficient. The dam breedtype comparisons were not sensitive to changes in prices paid for feed or the price received for the calf crop. The two backcross groups were generally intermediate, and showed net profits, suggesting a rotational crossbreeding system may be feasible. Reproductive performance in young dams was important, though some loss of reproduction could be tolerated if weaned calves had higher weaning weights. Utilizing heterosis appeared to be important. The crossbred groups all performed better than the straightbred group. For a northern range cow/calf production system, dams with maximum heterosis or the more intermediate types realized greater economic returns. (KEY WORDS: Simulation, Beef Cattle, Efficiency)

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Kathleen Jeanne Christensen Davis

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

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CHAPTER 1

INTRODUCTION

Beef cattle producers need information that will help them increase efficiency and profit for their operations. The research community has devoted considerable effort to find ways to enable producers to meet these needs. Systematic crossing of cattle breeds to take advantage of direct and maternal heterosis and complimentarity among breeds has contributed to increased and/or more efficient production in the commercial sector. It has been well documented that many crossbreds have shown increased growth rates, increased milk production, and earlier sexual maturity compared to parental straightbreds. Opportunities also exist to develop breeds or mating systems for specific management schemes. Recent emphasis has been on designing mating systems for specific production schemes and environments.

Limitations to producing crosses and testing traits of interest include the time and money involved in developing and maintaining herds of cattle. With more than 275 breeds of cattle worldwide and over 75 breeds recognized in the United States (Turner, 1988), the need for specialized reporting of types best suited to existing resources becomes clear. It is in this area that the computer is being utilized for simulation of different production schemes. Bourdon and

Brinks (1987) and Notter (1979) published results for biological and economic efficiency of cattle by simulation modeling. However, simulation model development depends on data collected, analyzed and reported for different breeds and management schemes. The researcher can then build a model that best represents those aspects of production which have meaningful relationships within the system.

The objective of the research reported here was to evaluate lifetime economic efficiency of five biological types of beef cattle in a northern range cow/calf production system. A computer simulation model, developed for data collected at the Northern Agricultural Research Center near Havre, Montana, was utilized to achieve this objective.

CHAPTER 2

LITERATURE REVIEW

The research community's main objective should be discovering and delivering useable information to livestock producers. This literature review illustrates the many diverse studies on systematic crossing of cattle breeds, the understanding of relationships among these studies required to make intelligent decisions for production systems, and how computer simulation may be of help in assisting producers in this decision making process.

Crossbreeding Studies

While not wishing to make a review of crossbreeding studies the main focus of this discussion, some time must be devoted to this area of research. A brief review of the literature (Armstrong et al., 1990; Belcher and Frahm, 1979; Chenette and Frahm, 1981; Dickerson, 1969; Fredeen et al., 1987; Neville et al., 1984; Rahnefeld, 1989; Rohrer et al., 1988; Sacco et al., 1989; Setshwaelo et al., 1990; Williams et al., 1990) shows the diversity of animal types and traits of interest available for study.

Subjects reported in these eleven studies included cow and calf weights, body condition scores, growth patterns, feed intake, calving ease, milk production, reproduction, 2-yr-old and older dam performance, heterosis, productivity defined in different terms, and net returns. There were eighteen cattle breeds used in several different mating strategies at eight locations in the United States and Canada.

Weight of cows and calves are easily obtained measurements that have been used as the basis for explanation of many different inputs and outputs in a production system. For the cow, mature weight helps explain feed intake required for maintenance and growth. It gives some boundary for birth weight of calves over which dystocia will more likely occur. The size of the cow is used in determining both her biological and economic efficiency.

Calf birth and weaning weights are similarly used in trying to predict efficiencies within a system. Higher birth weight is proposed as the greatest single factor in increased dystocia. Weaning weight is used as a measure of maternal ability. It is also used to estimate the overall efficiency of a breed, mating program or production system.

The use of weight to make predictions for a production system may pose problems for the producer simply because of the wide variation in weights of cattle of differing types. Mean cow weights in the previously mentioned studies ranged from 416 to 511 kg for first calf heifers and 435 to 737 kg for mature cows. Calf birth weights ranged from 28 to 42 kg and weaning weights from 155 to 231 kg.

Nutrient Requirements and Intake

Armstrong et al. (1990) reported feed intakes based in part on the size of the cow. A large, rotational cross (694 kg) had the greatest intakes with straight Hereford (574 kg) ranking lowest. A 4-breed terminal cross (613 kg) and a small, rotational dual purpose cross (565 kg) ranked second and third, respectively. These rankings remained the same during lactation and dry periods. The intakes measured did not follow the weight rankings in that the small dual purpose cross had a higher intake than the Hereford group, possibly due to the crossbred animals being young dams with higher growth requirements. The authors also felt that because an effort was made to adjust diets to maintain an average backfat measurement, reported animal intakes were 18 to 33% lower than requirements estimated from NRC (1984).

Comparisons of various F_1 crosses of Hereford, Angus, and Shorthorn dams by Charolais, Limousin, and Simmental sires, plus a Hereford x Angus cross control were reported by Fredeen et al. (1987) which related crossbred cow productivity to winter feed inputs at two locations in Canada. Energy requirements were estimated based only on body weight according to NRC (1976) but proved inadequate in the less intense management system during the first year of the study. Energy inputs were adjusted to 20% over NRC (1976) in an attempt to increase the body condition of these animals. The cows failed to maintain condition and a subsequent high mortality rate for both cows and calves, and low conception the following year was the basis for yet another 20% increase in energy over NRC (1976) estimates and a change in management from pasture grazing to drylot feeding. Cattle at both locations were fed in excess of estimated requirements in order to attain or maintain a minimum condition score in all cattle at both locations.

Deviations from the Hereford-Angus controls in energy inputs were generally comparable to the deviations in mean initial weights though there were exceptions. In the more intensive management system, all Simmental crosses and a Limousin-Shorthorn cross required more feed than their body weights would indicate, while all Charolais crosses in the harsher environment required less feed relative to the control.

Rahnefeld (1989) reported different growth patterns for young crossbred dams of similar breeding in these same environments. As might be expected, more intensive management in a less restrictive environment resulted in heavier animals during several stages of early production. The less restrictive environment resulted in a 3/4 Simmental-1/4 Shorthorn cross being heaviest, while in the harsher environment the 3/4 Charolais-1/4 Shorthorn was heaviest.

Jenkins and Ferrell (1983) compared the nutrient requirements to maintain mature weight of four breedtypes (Hereford x Angus reciprocal crosses, and Charolais, Jersey and Simmental sires bred to Hereford and Angus dams). These breedtypes were chosen to represent differing mature size and milk production potentials based on their mature weights and milk production levels. Animals were fed at low, medium or high levels of energy in drylot.

The Charolais, Simmental and reciprocal cross dams did not differ in weight throughout the study, but were different from the Jersey crosses which were smallest. Reported dry matter intakes at the low level of feeding (90 kcal metabolizable energy/kg metabolic body weight/day) were consistent with the weight rankings. However, at the high level of feeding (ad libitum), the Charolais cross dams had significantly lower dry matter intakes than the Simmental crosses and the Hereford x Angus reciprocals and did not differ from the Jersey crosses. A conclusion was that factors other than weight affected energy utilization and intake.

Maintenance requirements and energetic efficiency of Angus, Brahman, Hereford, Holstein and Jersey and their reciprocal crosses were measured by Solis et al. (1988). Among the straightbred animals, the Angus and Brahman had lower body weight maintenance requirements than the Holstein and Jersey, and the Holstein and Hereford had lower requirements than the Jersey. Of the crossbred animals, the Holstein x Angus, Jersey and Hereford had higher requirements than those of the Brahman x Hereford and Holstein and Hereford X Angus and Jersey.

While cow weight is commonly used in estimating feed requirements, several authors caution that differences may occur due to milk production potential, lean tissue mass, site of fat deposition and differing basal metabolic rates between *Bos indicus* and *Bos taurus* breeds.

Milk Production

Belcher and Frahm (1979) found significant differences in milk production among 2-yr-old dams of various breed groups produced by mating Angus and Hereford dams with Angus, Hereford, Simmental, Brown Swiss and Jersey sires. Those dams sired by Brown Swiss produced the most milk, followed by crosses of Jersey and Simmental sires on Angus dams. Reciprocal cross Hereford and Angus (control) dams showed the lowest milk production levels. These milk production traits echoed calf pre-weaning average daily gain (ADG) and 205-d adjusted weaning weights.

Chenette and Frahm (1981) reported significant differences among crosses involving Hereford, Angus, Simmental, Brown Swiss, and Jersey for early milk production by 4-yr old dams. The differences had dissipated by late summer and early fall most likely due to drought conditions. While milk production showed little difference later in the year, those dams that were heavier producers early in lactation raised heavier calves at weaning. Higher milk production paralleled higher weaning weights, but areas potentially limiting to the production system, including the feed requirements and subsequent reproduction of these animals due to differing levels of milk production, were not discussed.

Casebolt (1984) reported on lactation curves and milk production potentials for cattle with varying degrees of crossbred influence. The breedtypes included straightbred Hereford, two F_1 crosses (Angus and Simmental crossed on Hereford dams), and 25% and 75% Simmental x Hereford crosses. There was no significant difference between the two F_1 crosses, nor was there a difference between the two backcross breed groups. The F_1 crosses produced significantly more milk than the backcross cows. All crossbred dams produced more milk than the straightbred Herefords. It was also noted that the crossbred dams had more persistent lactation than the straightbred animals.

A study by Setshwaelo et al. (1990) included Holstein and Jersey breeds to determine the effects of high milking ability in crossbred dams. They showed no differences for calf gains from 1/4 Jersey dams as compared to Hereford x Angus reciprocal crosses. It was thought this was due to decreased mammary development as a result of the Jersey cross dams being raised by high milking dams themselves. If the maternal grandsire was Brown Swiss or Gelbvieh, the preweaning growth of the calves showed a larger deviation from the Hereford x Angus reciprocal crosses because of the greater growth potential of these breeds. When cows were sired by Holstein or Brahman (high milk potential), they showed no adverse affects due to poor mammary development, and benefitted from both maternal ability and growth potential.

Measures of Productivity

Defining productive longevity as the age at which a cow dies or is culled because she is incapable of producing a live calf, Rohrer et al. (1988) compared longevity and reasons for removal of straightbred and crossbred beef and dairy cattle at College Station, TX, managed in a beef production scenario. Results showed dairy breeds and their crosses exhibited earlier sexual maturity, and weaned heavier calves during their productive life, but due to the stresses of high milk production, these animals were more prone to mineral imbalances and disease which resulted in death or early removal from the herd. Inability to maintain body condition was also thought to contribute to lower longevity in these breeds.

Brahman breedtypes remained in the herd for more years than any other dam breedtype despite having the highest rate of removal for reproductive failure and a high incidence of uterine and vaginal prolapse as older dams. The experimental design was very lenient on culling due to poor reproductive performance, requiring the birth of at least one live calf every two years.

While traditional British breeds (i.e. Angus and

Hereford) and their crosses were most often removed for structural unsoundness, they showed greater productive longevity as a result of lower removal rates as young dams.

Sacco et al. (1989) reported results in terms of lifetime productivity (the total weight of calves weaned) for this same group of cattle. Straight Angus dams produced the greatest number of calves after four years of age and produced the most weaning weight adjusted per year of herd life. All straightbred Jersey dams had left the herd by nine years of age and Jersey and Holstein dams produced the least amount of calf weight per year of herd life. Brahman dams remained in the herd longer than other dam types but lifetime productivity was low owing to poorer reproductive performance. This agrees with results reported by Williams et al. (1990).

Animals that die have no salvage value, but young dams culled on reproductive performance generally have high resale value in the sale ring. However, the cost of replacing young dams is also quite high. In trying to interpret these results, it should be taken into account that the experimental design for these studies was such that many producers might have trouble implementing it.

Fredeen et al. (1987) reported significant differences in weight change and backfat between two locations which were believed to contribute to differences noted in lifetime productivity. Estimates of winter feed requirements per unit of calf weight weaned averaged 47% higher for the harsher, more restrictive environment. The large location differences in the energy requirements was attributed to the location differences in average cow weight at the beginning of winter feeding. Energy provided during the first year of the study was not adequate to maintain condition in the cows in the harsher environment. Of the breedtypes themselves, Charolais and Simmental crosses recorded greater productivity at both locations, and Limousin crosses showed lower productivity than the Hereford-Angus controls.

While this study only considered relatively high cost winter feed inputs, they felt it was indicative of overall production costs. One consideration not addressed was stocking rate for fixed land resources. If the location limits the number of cattle and calves that can be produced, returns may not cover costs of production.

Armstrong et al. (1990) reported a large rotational cross showed the highest weaning weights and the greatest net returns when compared to purebred Herefords, a small, rotational dual purpose cross, and a 3-way rotational cross. The small rotational cross ranked third in weaning weight produced but second in net returns. Constraints to the system influenced net returns when comparing the straight Hereford to the terminal cross. Feed constraints gave the Hereford dams the advantage since more animals could be maintained on the same amount of feed and the higher weaning weights of the terminal cross calves did not offset the additional feed costs required. However, when herd size was the constraint, the terminal cross system showed higher profits due to increased output per cow. Final inferences stated neither body size nor feed intake alone were good indicators of net return.

Setshwaelo et al. (1990) reported no differences in conception rate among 3-breed cross females utilizing seventeen cattle breeds, possibly due the high (94%) overall conception rate making it difficult to detect any differences that may have been present. Heterosis of the crossbred dams and culling policy most likely combined to result in this high rate.

Calf weight weaned per cow exposed to breeding in this study (Setshwaelo et al., 1990) showed large and positive deviations only for Holstein (40 kg) and Brahman (21 kg) sired dams. Maternal grandsire effects were not included due to large sampling errors. Body condition scores were negative for all breeds but Brahman, Devon, Charolais and Simmental. The dairy breeds are believed to have lost condition as a result of their high milk production. Because feed requirements were not measured, the authors caution making any decisions based on these deviations. The results only suggest the direction of deviations in efficiency from the control group. Those animals with the most output were also larger and produced higher levels of milk indicating a need for greater input levels.

Belcher and Frahm (1979) also reported that milk production levels had an effect on dam body condition scores for 2-yr-old dams during the lactation period with Jersey and Brown Swiss crosses being thinnest and the control being average. Summer weight gain was not different among breed groups. Productivity, defined as total calf weight weaned per cow exposed, showed Simmental x Hereford crosses to be lower than the control group while Simmental x Angus crosses were higher. Jersey crosses and Brown Swiss x Angus dams were most productive.

Rebreeding performance was not closely related to milk production across breed groups. Brown Swiss crosses, with their high level of milk production, did show low reproductive levels while Jersey cross dams, also with relatively high milk production levels, had the highest reproductive performance. It was suggested some of this difference might be due to differences in maturing rates, and could change in mature cow analysis. While it might be expected that higher productivity, i.e. greater calf weight weaned per cow exposed, would translate to higher returns, no estimates of inputs to maintain the differing levels of milk production were presented.

Calf Birth Weight

Birth weight is most often related to calving difficulty and the subsequent affects on a production system. Setshwaelo et al. (1990) found all breed deviations for birth weight were positive except for Brahman and Jersey, and closely related to mature dam size except in the negative maternal effect of Brahman sired dams and a positive grand-maternal effect of the Red Poll breed. The Brahman crosses subsequently had lower calving difficulty scores due to small calf size compared to dam size. This study suggested those dams with 1/4 Hereford breeding had less calving difficulty than those with 1/4 Angus breeding.

Neville et al. (1984) reported results in an experiment involving straightbred, two-breed, and three-breed rotational crosses of Angus, Hereford and Santa Gertrudis in Georgia. Birth weights were highest for Santa Gertrudis followed by Hereford and Angus for each of three generations present. Birth weights increased as generations of rotational cross breeding advanced. In partitioning this trait into additive effects, the Angus crosses showed a negative deviation and the Santa Gertrudis crosses showed a positive deviation from the Hereford breed in all generations. For the maternal component, both crosses showed negative deviations.

Calf Weaning Weight

Weaning weight is considered an important trait because it is the main saleable product of the cow/calf system, and because of its correlation to yearling weight and growth for feedlot operations. Weaning weights are very often reported not only in terms of breed, but also in relationship to the milk production of their dams.

Armstrong et al. (1990) ranked calf weaning weight from a large rotational cross first, followed by a 4-breed terminal cross, a small rotational cross and straight Hereford, in that order.

Setshwaelo et. al. (1990) compared deviations for several three-breed cross dams from Hereford x Angus reciprocal crosses for sire and grandsire effects on cow and calf performance to weaning. Breed deviations for dam weight were positive and significant for all sires except Jersey, Red Poll, Limousin, and Angus. The mainly positive breed of sire and maternal grandsire effects were attributed to higher individual genetic potential for growth and mature size from the other sire breeds.

Neville et al. (1984) reported that weaning weights in their rotational cross breeding experiment followed the same pattern as birth weight with weaning weight increasing as generations advanced. The Angus maternal effect was positive while the additive effect was negative when compared to the Hereford group. Santa Gertrudis showed positive effects for both maternal and additive effects. Neville et al. (1984) reported that when results were based on weight weaned per cow exposed, only in the first (straightbred) generation did the Santa Gertrudis outperform the Hereford and Angus dams. Weaning rate was similar during the first generation, but declined in the two- and three-breed rotations. Again, the second and third generations showed increases over parental types for this trait. Conclusions were that two- and three-breed rotational crossing was effective in increasing traits of interest though the three-breed rotation showed no significant advantage over the two-breed rotational system.

If a production system's success were dependent on only one of the traits discussed, selection of a breed or mating system to meet a single production goal such as heavy weaning weights or slaughter endpoint in the shortest period of time would not be overly difficult. Because of complicated interactions between various traits, however, it is far from easy to make decisions which will result in successful management of a system.

While all the above mentioned traits (and many more) are important aspects of cattle production, interpreting the results can become complicated and time consuming. Decision making for the producer would involve combining information from several different reports dealing with expected input and output parameters. Many producers may not have the time to sort through the myriad of information generated. It must also be remembered that what works in one part of a country in a certain production system may not necessarily transfer to a different area with any success.

Long (1980) published a review of experimental results from various crossbreeding studies, and concluded mating systems should be designed for specific production systems and environments. Utilizing data already reported, researchers have been able to construct computer models that combine several traits within different management schemes.

Computer Simulation Modeling

Modeling is simply another way of trying to equate biology into a system whereby inferences can be made about some aspect of production. Spedding (1987) defined modeling as

> "an abstraction and simplification of the real world, specified so as to capture the principal inter-action and behavior of the system under study and capable of experimental manipulation in order to project the consequences of changes in the determinants of the system's behavior".

Dent and Blackie (1979) define a model as a physical representation of a real object, such as toys, scaled mock-ups of buildings for later construction, or the chemists greatly magnified model of a molecule. In animal research for example, sheep, being smaller, less expensive to maintain, and easier to work with, might be used as models for cattle because they are both ruminant livestock species. They further define the computer simulation model as a symbolic representation of real life. The symbolic type of model is abstract, having no physical resemblance to the system it represents.

The computer model may be used because of the speed at which calculations can be made, its capability for handling many equations and concepts systematically, and its ability to re-evaluate these equations over many replications in relatively short periods of time. We can model many input variables such as culling strategies, herd size, diet compositions, and mating systems. Some variables that may be difficult to model precisely include individual animal variation, weather factors and current market structures (prices). These inputs may be accounted for by including wide ranges of values for the variable, or by assigning a random variation to them.

There are different construction methods for simulation models including empirical, deductive or mechanistic, deterministic, and stochastic. Each type has benefits and limitations associated with it.

Empirical Modeling

The empirical model is based on data obtained from actual experimental results, such as a feeding trial or mating system. Through statistical analysis of group comparisons, discriminant variables, or regression techniques, equations are developed to describe variables in the data set. These equations may help explain an actual biological relationship, or may only show a statistical relationship between variables that has very little biological meaning. They often show how descriptive variables are related, but not why they relate as they do.

In an early modeling experiment, Whittemore and Fawcett (1974) published their account of model development and results of simulation for responses of growing pigs to differing protein and energy inputs. Using various sources reported in the literature, they developed mathematical equations to describe deposition of lean and fat tissue in young, growing pigs under the hypothesis of first meeting maintenance requirements, secondly laying down lean tissue according to protein availability, and lastly using excess protein and energy for fat deposition. A sensitivity analysis was conducted to determine if any input variable might be excessively affecting the output. Validation was by comparison of simulation output to published results comparable to model parameters.

Though overestimation of lean tissue deposition and underestimation of fat deposition occurred, their results were in good agreement for direction and magnitude of change with the actual feeding trials they were compared to. The discussion of results stated errors would result if components of the model were not constant over ranges examined, if the equations used were inadequate to explain actual biological systems, or if the values chosen were invalid.

The main areas of suspicion related to using a single expression for maintenance cost, and in the estimation of efficiency of protein utilization. They felt the model demonstrated an ability to predict responses to dietary inputs, and would be useful in interpreting experimental results.

Jarrige et al. (1986) developed an entirely empirically based model for prediction of voluntary intake in ruminant animals. The goal was to assimilate information available into a system for dealing with intake on the same basis as energy and protein feeding, assign a single value for intake capacity of animals regardless of feed quality, and assign a single value to each forage regardless of animal status. The unit developed was the "fill unit".

Literature references provided voluntary dry matter intake values for 2331 different forages by Texel wethers. Data from 137 feeding trials were used to develop the voluntary intake of "standard" cattle. These values were assumed to represent the intake capacity of the animals. A substitution rate of concentrates for forages was also calculated. Digestibilities for forages were determined at several stages of development and a reference pasture grass was defined.

Some potential problems with the development of this model were small numbers of animals in feeding trials which may not account for the variability among animals within a species and whether the forages measured were collected over a long enough time frame to account for year to year variation. The model was not tested, or validated, on an independent data set since all available references were used in formulating the equations.

The authors caution that the system is based on intake restricted by fill, hence it cannot be used to formulate diets containing large amounts of concentrates. They also point out the data used to develop these equations were derived from experiments being conducted for other purposes. Individual feeding trials will not take into account social factors when animals are group or pasture fed. The relative value of findings derived from this program are inherent on the number and quality of the data base.

Many areas of research are quite specialized, dealing with only one aspect of a total entity. When conducting a nutritional study, diets are manipulated to reflect changes in a given set of constraints. There may be no attention paid to how one variable might affect a different area than the one under study. The empirical model has been useful in that it has enabled researchers to utilize published data to formulate equations which relate several different areas within a system. The major danger of these models lies in the fact that they are bound by the input which was derived from the data. If the numbers do not, in fact, explain the biological system, the empirical model will not reveal that fact but simply mimic the input parameters. Another type of modeling, termed deductive or mechanistic, attempts to overcome some of these restrictions.

Deductive Modeling

Deductive modeling has developed in an attempt to explain the causal relationships between components of a biological system. The modeler is not satisfied knowing how traits are related, but why. It may come about when a researcher's area of interest has no literary references available. Through personal knowledge and intuition, the scientist may develop a theory believed to explain the nature of a relationship. The deductive model is developed to test the hypothesis, then comparisons of output to a real life situation can be made.

An argument for development of mechanistic models was submitted by Sauvant (1987). Noting that most empirical models relating dry matter intake to milk production of dairy cattle cannot be applied outside their specific constraints (particularly the diet) without losing accuracy, he proposed inclusion of models which would account for biochemical conversions during digestion and metabolism. Development of these types of models will require intimate knowledge of the chemical reactions that occur between ingestion of feed and final milk output. Models for specific organs and metabolic pathways may be combined into the whole animal model and offer explanations and predictions for feeding the dairy cow to optimize production for different environments and systems.

Whittemore (1986) also proposed that deductive modeling should be developed in order to identify the questions which need to be asked. He stated that it was better to form an opinion of how biology works and then test the proposal than to measure traits and form regression equations believing they explain all that needs to be known. For example, he suggested that early growth in pigs may be much faster than data available from experimental results suggests. He proposed modeling growth independent of animal weight and age, rather defining circumstances in which the animal does not become fat. He also stated that construction of a well thought out, complete model will point to areas of research that are irrelevant, in conflict, or lacking. Finally, he proposed that once the model is built and working, it can be used to predict the responses of real life experiments, or even be used instead of the experiment. Whether an individual model can fully explain all aspects of a system well enough to be the experimental unit is a decision to be made by individual scientists.

Many times a combination of empirical and deductive methods will produce productive results.

Combining Modeling Techniques

A good example of a combination of modeling methods was presented by Bennett and Leymaster (1988). Noting that the description of litter size of swine as the product of ovulation rate and embryo survival failed to address an area of reproduction they believed to be important, they developed a model based on the hypothesis that uterine capacity also played an important role. They believed that if their theory was valid, it would be possible to determine a mean and variance for the trait, and also generate phenotypic and genetic variation.

Data available on estimates of ovulation rate and litter size at birth were incorporated into the model. Embryonic survival was divided into two phases. The first was defined as loss due to failure of fertilization of ova, abnormal development, genetic lethals, etc., and was estimated by summarization of reported values. The second phase was considered to be loss of viable embryos due to limited uterine capacity. Because no data were available as to when capacity would begin to limit litter size, a value was arbitrarily assigned and was not intended to reflect a known biological constant.

Two thousand simulations for each of 25 combinations of means for ovulation rate and uterine capacity were generated. Simulated statistics were then compared with reported experimental data for validation of the model. They were able to make a good argument for their hypothesis.

Marshall et al. (1985) also developed a model by using various sources of information from the literature and adjusting values to reflect their understanding of the system that was being modeled. Mathematical equations were developed to predict various trait responses affecting productivity and profit for a cow/calf/feedlot system. Different culling and selection strategies, also based on the modelers' views of important traits, were simulated for a 15 yr period. Their goal was to evaluate the long term effects of these different strategies.

Productivity was measured in terms of weaning weight and yearling weight produced, and the number of calves weaned per cow exposed to breeding. Profit involved cumulative profit to weaning and feedlot endpoints, and cumulative profit per cow per year for both production systems.

Findings from the study illustrated the effect of changes in independent variables on profit or measures of production. Management, selection, and changes to a production system will greatly affect subsequent outcome. Trade offs occurred between the more efficient use of feed by younger animals and the greater reproductive performance of older dams.

Use of available data and personal intuition in combination with modeling techniques may offer valuable insights for the further direction of experimental research. This requires well thought out use of available resources and an understanding of the many components within any type of system, and their effect on other components involved.

Any of the systems that have been discussed may be utilized within two other types of modeling techniques; deterministic and stochastic modeling procedures.

Deterministic Modeling

Deterministic modeling describes a model wherein the value associated with a trait or used in an equation does not vary; for example, individual animals versus the mean of a contemporary group. This approach to modeling does not, however, exclude variation due to time, age, or other factors. By incorporating data from several studies, mean values for traits of interest can be determined from different forms of analyses of the data. By inclusion of several values for the traits, mean response to change can be determined. Dent and Blackie (1979) have cautioned that deterministic models can only generate information on the mean response of the real system to a change in one of the variables.

Results from several examples of complex deterministic models have been reported in the literature (Notter et al., 1979; Tess et al., 1983; Bourdon and Brinks, 1987;). Complex systems were modeled in all cases.

Notter et al. (1979a) stated a primary goal of research is identification of genetic material and mating and management systems which, when combined, will minimize production costs for specific environments. This would require evaluation of all sources of costs and returns to the system. With all the types of cattle and management systems available, experimental evaluation of all combinations would be severely limited by the resources required. They proposed use of the simulation model to synthesize and extrapolate on information available from several sources for a cow/calf/feedlot enterprise in the midwestern area of the United States.

Simulations began with a modified version of the Texas A&M Cattle Production Systems Model (Sanders and Cartwright, 1979). Full details of model development, equations and systems were reported in a series of papers examining differing levels of milk production, cow size and mating systems. Three levels of maximum milk production (Notter et al., 1979a) were simulated for each of three mature weights (400, 500, and 600 kgs). Comparisons were made within cow size. The level of milk production affected reproduction, body condition, puberty, and weaning weight and rate. Biological efficiency was improved with increasing levels of milk production only if weaning rates were also improved. Economic efficiency suffered from increased milk production if it reduced weaning weight per cow exposed.

Effects of cow size were simulated for three weights (400, 600, and 800 kgs) each in two management systems for "ideal" and less favorable environmental conditions (Notter et al., 1979b). Mature size affected age at puberty, weaning, and slaughter. In their opinion, differences in economic efficiency were due to the interaction of mature size with management choices and prices paid for the products, and not inherently due to the biological effect of size.

Mating systems analyzed by Notter et al. (1979c) were purebred and two- and three-breed specific, and rotational crossing systems. Size of the sire was based on mature weights for females of the breed (500, 600,700, and 800 kgs). Two levels of milk production were also simulated. Biological and economic efficiencies were affected by incidence of dystocia due to the size of the sire, levels of heterosis within the mating system, milk production, growth rate, and the prices of feed relative to the system. Systems utilizing heterosis were more economically efficient, and systems which also used maternal heterosis were even more efficient.

Conclusions reported in all the papers were to be applied only to the management systems simulated, and offered guidelines rather than biological truths. If the environment or management was not extremely similar, further simulations and adjustments or assumptions would need to be made. Individual animals were not simulated, thus animal variation could not be included or measured.

Bourdon and Brinks (1987a,b,c) also published a series of papers reporting efficiency of production of beef cattle in a range environment using a modified version of the Texas A&M University Beef Cattle Production Model (Sanders and Cartwright, 1979). Again, growth rate, milk production, and reproductive traits were addressed along with different culling strategies and management options. The modified model was completely deterministic. Birth weight, yearling weight, mature weight and milk production levels were traits used in development of 12 genotypes. Genotypes simulated were not meant to represent any specific breed of cattle.

The importance of milk production for the beef cow in this model was dependent on the feed costs and production system (Bourdon and Brinks, 1987a). Efficiency increased with increased milk production if calves were marketed at weaning. When animals were retained to slaughter, high feedlot costs compared to low feed costs for the cow herd also favored increased milk production in the dams.

Production efficiency did not increase substantially with early puberty and associated increased fertility (Bourdon and Brinks, 1987b). The advantages of increased longevity were negated by the decreased efficiency of maintaining mature dams.

A bioeconomic model was constructed by Tess et al. (1983a) in an attempt to simulate effects of nutrition, genetic change, physiology, and economics in the life cycle of a pork production system. The model was a combination of empirical and deductive techniques. Simulation began with baseline levels of performance for crossbred hogs in a midwest production system.

The model addressed growth from birth through final disposition, and was divided into fat and lean body mass. Because very little research had been done on deposition of fat and lean during the early growth of pigs, equations for rate of fat and lean deposition were developed from serial slaughter experiments. Estimates for metabolizable energy (ME) were also adjusted to account for higher maintenance requirements for pigs with leaner carcasses.

Other traits modeled were age at puberty, conception rate, ME required for gestation and lactation, litter size and weight, survival rates, pre- and post-weaning growth of the pigs, body condition of the sows, management options, and economic input and the interactions of the traits with one another. Economic returns were based on average prices for market hogs and cull sows.

Validation is considered an important aspect of the modeling process. Incorporation of data not used in model construction is generally used to assess the accuracy of the model. Because no experimental results were available for the scope of the model developed by Tess et al. (1983a), validation was not possible. The authors gave alternate methods of evaluation of the design. Detailed descriptions of input parameters for several points in the life cycle of the production system offered some verification of the model. Because the model was constructed for these several points of production, comparison of simulated results with experimental results of the same type were also possible. The authors offered several comparisons of certain aspects of simulation with published reports for the same traits. They believed the model adequately represented the characteristics involved with growth and the production boundaries represented.

Selection for a specific trait or a combination of traits will be best accomplished if the traits chosen also account for changes which may occur in another area of the production system. Simulations generated by this model were used in an attempt to ascertain the relative value of genetic change for several measures of efficiency within a production system (Tess et al., 1983b).

Efficiency was described in terms of biological and economic measures, ME required and cost per 100 kg of empty body weight and carcass lean produced. The response to changes in the genetic level of a trait were simulated by increasing or decreasing the mean values from the base level used in construction and verification of the model. Because the response to independent changes would only describe the area being changed, attempts were made to quantify the interactions of the genetic components over the total range of the production system.

Some areas of discussion presented included indications that maternal traits might be more important than previously thought in increasing the economic efficiency of a system. The definition of value for the output is also extremely important in determining the traits used for selection. While no premium is as yet paid for lean carcasses, consumer demand for lean meat is not likely to disappear. The simulations showed significant differences relative to value between empty body weight and weight of carcass lean.

The goal of the research team was to provide guidelines in making selection decisions. The results would not be valid in specialized breeding systems. They also hoped to identify areas for further research and communication between the several disciplines within the animal science community.

The models discussed have attempted to address several areas of production systems and the biology of the animals which affects the results. In evaluating the use of deterministic models, Dent and Blackie (1979) point out there is no error term for use in computing F tests in analyses of variance or confidence limits. Data used to develop a model will always have error associated with variables not considered, imprecise measurements of biological or economic traits, lack of fit of statistical functions and biological variation. The results are restricted by the values used for construction. Some decision making may require more than the mean response due to a change in one variable. Incorporating randomness into the model is accomplished by including stochastic variables.

Stochastic Modeling

Dent and Blackie (1979) offer some good guidelines for use of stochastic variables in modeling. Historical data may not be available or be of a limited time frame. This type of data may also limit research in that effects of events not recorded or occurring in a different sequence might be omitted. The alternative to using historical data is to create the values as stochastic variables. These values are randomly generated from within a probability distribution derived from analysis of available data. Care needs to be taken that these values represent the variables within the real system under review.

Lamb and Tess (1989a) published results from stochastic modeling of crossbreeding systems within small beef herds (30 dams or less) using one sire per year. Small herds of cattle must deal with problems not inherent to larger production systems such as availability of replacement females due to the variation in sexes born each year. Use of complicated or multi-sire crossbreeding systems are also impractical. This study evaluated alternative crossbreeding systems specifically for the management of small herds of cattle utilizing a purebred, two- or three-breed rotations using natural service sires and artificial insemination breeding, and a four-breed composite. Inputs were assumed similar and comparisons were made based on differences in utilization of heterosis as it affected weight sold. Differences in natural breeding and artificial insemination would reflect loss of production due to incorrect matings.

The maximum age for culling dams proved to be 12 yr. When the maximum age was reduced, changes in the ratio of sexes resulted in too few animals to maintain herd size.

Heterosis increased when matings were correct and the number of breeds used increased, and measures of performance ranked the three-breed rotation and the composite higher than the two-breed rotation. However, the variation in calf weaning weights due to the differing breed composition from cows of several generations and the expression of heterosis showed no consistent deviations. There appeared to be no basis for recommending any of these crossbreeding systems over another in small herds.

A companion paper (Lamb and Tess, 1989b) reported results for herds of 50 cattle or more using two-sires per year. The nine production systems included the use of complimentarity among breeds through the incorporation of rotational-terminal systems. Artificial insemination was not meant to compare advantages due to selection of superior sires.

The inclusion of the rotational-terminal systems did not provide sufficient increases to production to warrant their recommendation over rotational systems. The roto-terminal systems were sensitive to changes in the sex ratio of calf production. These results point to another area of management problems for the small herd producer. While no expenses were included to account for the additional labor required for artificial insemination, the results reported indicate any advantage to this breeding system would be through the increased genetic potential of the sires selected, not through increased heterosis.

The results of these studies indicate a two-breed rotational production system would yield satisfactory improvement over a purebred system owing to the random variation within the more complicated systems addressed.

Modeling has strengths and weaknesses as does any area of research. Organization of concepts into a framework for understanding is possible. We are able to study systems that do not exist or that may be too expensive to maintain and replicate. Long-term effects are within our boundary because the time-frame of the simulation is a controllable input.

However, the model may require simplification of a system because available data on or knowledge of important inputs is lacking. Using various data sources to estimate input parameters may not be an ideal situation from the researcher's point of view. Finally, validating, or "proving" what we have modeled is a true representation of real life is frequently impossible.

Construction of the model may point to areas where information is lacking, thus giving researchers new guidelines for future experimentation. If the researcher has used valid, unbiased results from the literature or has used a valid database, then the computer model is adequate if it answers the questions that were addressed.

Havre Research

Researchers at Montana State University initiated a long term study for comparison of cattle types differing in mature size, milk production potentials, and levels of crossbreeding. The data for this study, recorded at the Northern Agricultural Research Center near Havre, Montana, included milk production, body weights for cows and calves, pregnancy rates, occurrence of calving difficulty and survival rates for five biological types of dams raising terminal cross calves which could be integrated into a simulation model.

The first phase of the project involved development of the dam breedtypes. Lawlor et al. (1984) published results for the preweaning growth and survival of these cattle. They found the breed group of the calves was a significant source of variation for gestation length, birth weight, calving difficulty, late survival, percent of calves weaned per cow calving, 180-d weight, 180-d height and the weight:height ratio. Differences were due mainly to the 50% Simmental-50% Hereford calves having higher birth weights, experiencing more difficult births, having heavier weaning weights and being tallest at weaning. The 50% Angus-50% Hereford calves showed an advantage in net kilograms weaned per cow calving. The authors concluded that benefits obtained by higher growth potential could be reduced due to differences in survival rates.

Kress et al. (1984) also looked at the effect of these calves on their dams (straightbred Herefords). They found cattle raising crossbred calves gained less weight, had lower body condition at weaning, exhibited smaller gains in weight change per unit of height and experienced lower pregnancy rates than those dams raising straightbred Hereford calves. The calves sired by Simmental bulls had the greatest influence on the dams.

The next phase of the experiment involved the postweaning phase and heifer development to breeding. Steffan et al. (1985) reported on heifer postweaning growth traits and early reproductive performance. The 50% Simmental heifers showed the greatest ADG with 50% Angus and 25% Simmental heifers intermediate, and straightbred Hereford heifers exhibiting the