A SYSTEMS APPROACH TO BEEF IMPROVEMENT

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Introduction

> *"To obtain understanding, we need to supplement the quantitative techniques brought to us through the march of science, with the artistic understanding of qualities that our obsession with science has brushed aside."*
>
> Roger Martin, 2010, Dean of the Rotman School of Management, University of Toronto

From many important perspectives, beef improvement efforts since World War II, particularly the Beef Improvement Federation's work over the last 42 years, have resulted in tremendous progress. Cattle reproduce more frequently and grow faster and more efficiently than their ancestors of little more than half a century ago. In many respects, the meat products these cattle yield are not only healthier than in the past, they are well accepted in a complex, consumer driven world economy. To a large extent, these changes are the direct result of a linear, scientific approach. This reductionist approach might best be described as an elaborate attempt to solve a complex puzzle by searching for missing puzzle pieces. The puzzle is analogous to the quest for beef improvement. The pieces represent the genes identified and associated with economically important traits. The puzzle is generally accepted as solved by either increasing gene frequency for important traits or by increasing those traits' dominant allele. The two primary tools used to accomplish this noted beef improvement have been the use of breeding systems and the application of the principles of animal selection. Over the last four decades, the popularity and use of breeding systems has waxed and waned. However, the application of the principles of animal selection has only gained momentum and prominence. Progress via animal selection is limited by three critical constraints. The first is selection differential. The second is generation turnover. The third is the heritability of the trait of interest. Since heritability is generally accepted as fixed, changes in gene frequency are due primarily to the identification of outstanding individuals and the accelerated diffusion of their genes into the population through various techniques and technologies. Therefore the success of this "puzzle" approach to beef improvement has been and remains dependent on the constant development of more advanced technologies. From simple ratios of key metrics to whole animal genomic panels, piece after piece has been added to the puzzle, whose success is widely understood to be change.

But what if beef improvement was approached not as a puzzle, whose solution was just a technology away, but as a mystery? In his provocative book *What the Dog Saw*, author Malcolm Gladwell challenges the reader with such a question (Gladwell, 2009). Gladwell suggests that puzzles are "transmitter dependent, they turn on what we are told." That is to say, solutions to puzzles depend on "pieces." In this case, in order to improve beef, the cattle industry has been dependent on the regular transmission of techniques and technologies that fall into one of two categories. The first are technologies that aid in the identification of individuals that possess unique characteristics in order to increase the selection differential of a breeding program. For example, ratios, breeding values, EPDs, genetic markers, and whole animal panels are all designed to aid in the identification of animals with traits that deviate from the average of the population. The second category of techniques and technologies speed the diffusion of a selected animal's genes through a population. These techniques and technologies include rapid generation turnover, artificial insemination, estrus synchronization, sexed semen, embryo transfer, and cloning. And so, with this puzzle approach, beef improvement has been and remains dependent on the regular transmission of techniques and technology derived from science and industry.

In contrast, Gladwell (2009) says that mysteries are "receiver dependent, they turn on the skills of the listener." In the case of beef improvement then, his message challenges an industry to be thoughtful and contemplative in its application of techniques and technologies by honing its skills of listening and understanding. For example, is the most economical and effective way of improving beef accomplished by manipulating the bovine genome to increase gene frequency? Or could it be the mechanical treatment of the meat itself? Could it lie with the emerging field of epigenetics? Or perhaps it lies "back to the future" in a learned application of the principles of breeding systems? Perhaps it lies in the thoughtful and strategic combination of multiple strategies. The successful development, evaluation, and application of complex strategies to unravel the "mystery" of improving beef requires knowledge and skills in fields not generally associated with the historic work of beef improvement. Examples are micro and macro economics, managerial accounting, system dynamics, and systems thinking; fields whose mastery is "receiver dependent."

Complex Systems

> *"Society has become so complex that traditional ways and means are not sufficient anymore. Approaches of a holistic or systems nature have to be introduced."*
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> Ludwig von Bertalanffy, (Laszlo, 1972)

Bertalanffy's challenge resonates with a beef industry that struggles with profitability across its many segments and, perhaps even more importantly, shrinking cattle numbers that threaten its place in a dynamic economy. These powerful trends, that seem to have a life of their own, clearly represent a serious challenge to the stability of the entire beef industry. The choice then is to approach this challenge as either a puzzle or a mystery. If this daunting challenge is viewed as a mystery to be unraveled, it needs to be understood as a complex system. But what is a complex system? Hall and Fagen (1968) classically defined systems as "a set of objects together with relationships between the objects and between their attributes." They define objects as "the parts or components of the system," attributes as "properties of the objects," and relationships are the things that "tie a system together." Waldrop (1992) describes systems as networks of agents acting in parallel, but interacting with each other in a system, where nothing is fixed and control is highly dispersed. Providing deeper elucidation, MIT professor John Sterman (1998) described five fundamental characteristics of a complex system:

1. They are tightly coupled: everything influences everything else.
2. They are dynamic: change occurs on many scales.
3. They are policy resistant: obvious solutions to problems fail or actually make things worse.
4. They are counterintuitive: cause and effect are distant in time and space.

5. They exhibit tradeoffs: advantageous short-term behavior is often different, or even antagonistic, to advantageous long-term behavior.

Is the work of improving beef a complex system? Based on the definitions and characteristics listed above, it clearly is. Evidence abounds. Many of the economically important genetic traits of beef cattle are correlated with each other. However, some are antagonistic. Phenotypic change may exhibit itself in the first calf crop following a mating, or many years later in the offspring of those calves. After generations of work to increase the percentage of "choice" cattle in the marketplace, their proportion in the population of the fed cattle marketed remains remarkably the same (Rhoades et al., 2008). The lethal genes associated with dwarfism in Hereford cattle in the 1950's, and more recently with curly calf in Angus cattle, provides classical examples of how rational decisions related to animal selection may have unexpected and unpredictable consequences that exhibit themselves decades later. Increasing the growth traits of cattle through selection and breeding systems in the 1970s provided a short-term benefit for individual cattle producers as they increased the pounds of beef for sale from their ranches and farms. But as consumer demand for beef dropped precipitously in the 1980s and 1990s, the oversupply of beef only added to severely depressed prices for cattlemen. The question becomes; why does the beef industry and other complex systems behave the way they do?

MIT Professor Emeritus Jay Forrester described the following principles of complex systems that offer insight into this question (Sterman, 1998).

- The nature of "feedback" tends to mislead people into taking ineffective and even counterproductive action.
- People do not understand the complex interactions in a system and cannot correctly predict the outcome of their actions.
- Most difficulties are internally caused, even though there is an overwhelming tendency to blame outside forces.
- The actions people take, usually with the belief that the actions they take are a solution, are often the cause of the problems.

Continuing to approach complex systems like beef improvement as simply the cause and effect of selected parts is naïve, misleading and problematic (Senge et al., 1994; Goodman 1994). There is important intrinsic value in viewing things like beef improvement as a complex system (Senge, 1990; Leibold et al., 2005; Haines, 2009). It clearly contains fundamental elements of several foundational sciences including biology, ecology, economics, and human behavior. To solve the mystery of beef improvement, the basic relationships between the fundamental elements of the system are as important, if not more important, than the foundational science of any of the component parts.

Beef Improvement as a Complex System

"The weather never settles down. It never repeats itself exactly. It's essentially unpredictable more than a week or so in advance. And yet we can comprehend and explain almost everything that we see up there. We can identify important features such

as weather fronts, jet streams, and high-pressure systems. We can understand their dynamics. We can understand how they interact to produce weather on a local and regional scale. In short, we have a real science of weather without full prediction. And we can do it because prediction isn't the essence of science. The essence is comprehension and explanation.

Waldrop (1992)

Epigenetics. What might beef improvement look like if it were approached as a complex system? Perhaps it would include an application of the principles of epigenetics. The definition of the Greek prefix epi means "on, upon, over, above, after, near, beside, and after" (The American Heritage Stedman's Medical Dictionary, 2010). Epigenetics are mechanisms that seem to allow an organism to respond to its environment through changes in gene expression (Jaenisch and Bird, 2003). They are the mechanisms that come into play "after" genetics. As a field of study, epigenetics is the exploration of how genes are expressed, and occurs both pre and postnatally as well as long into adulthood (Jaenisch and Bird, 2003). It is now widely held that gene expression is modulated by outside forces (Shenk, 2010). For example, the diet of a pregnant woman can affect her offspring's susceptibility to disease (Hazani and Shasha, 2008). The diet of an individual can affect his or her susceptibility to cancer late in life (Jaenisch and Bird, 2003). Also, and contrary to current dogma, heritable variation can arise as a response to the environment, and is not always random (Shenk, 2010).

The study of epigenetics during pregnancy is often referred to as developmental programming or fetal programming. A growing body of work from the University of Nebraska (Stalker et al., 2006; Martin et al., 2007; Larson et al., 2009) provides clear and compelling evidence of fetal programming in beef cattle production systems. In particular, protein supplementation of pregnant cows improved weaning weights of calves (Stalker et al., 2006), the fertility of their female progeny (Martin et al., 2007), and the health and some carcass characteristics of male progeny in the finishing phase (Larson et al., 2008). In their review paper on the effects of maternal nutrition on fetal growth and the performance of their progeny, Funston et al. (2009) offers sophisticated explanations concerning how the mechanisms of fetal programming work. This is extremely important work, because a widely adopted strategy to improve profitability has been to lower winter fed costs by cutting or lowering supplementation levels. It also provides an excellent example of how, in a complex system, short-term results may be different than long-term consequences. In this case, lowering feed costs during pregnancy may improve profitability in the near-term, but decrease profitability in the long-term. It also provides evidence that, in complex systems like beef improvement, cause and effect are distant in time and space.

There is also compelling evidence of the role of epigenetics in growth and development after parturition. Long thought to occur late in the finishing phase, marbling is now recognized to begin at a relatively young age and progresses at a constant rate through the finishing phase (Bruns, 2004) and can be improved by creep feeding (Myers et al., 1999). However, in contrast to the effect of pre-partum nutrition on improving a heifer calf's productivity as a cow, in a 21-year study, creep feeding adversely affected lifetime productivity of cows (Martin et al., 1981). It would seem then that improved nutrition affects animal performance differently depending on sex and whether supplementation occurs pre or post partum. Interestingly, aggressive implant treatments affect marbling differently, depending on the age of the animal when they are administered (Bruns et al., 2005). These examples are clear evidence, that regardless of an animal's genetic propensity, its actual phenotype can be affected by not only by its physical environment, but by exogenous factors, like pre and post partum nutrition and hormones, that control the biochemical processes required for gene expression.

Learned Behavior. What if the observations made concerning animal production and performance were not due to the genetics of the animal, the environment in which it is living, or epigenetics, but instead to learned behavior? Clearly, in confined animal production, where an animal's nutritional needs and immediate physical environment are controlled, this is not relevant. But consider production systems on pastures or rangeland. The science of herbivory is based on the assumption that all animals in the population behave predictably, as reflected by treatment means, which are then extrapolated to populations (Provenza, 2004). Variation within treatments is treated as a statistical problem to be dealt with mathematically, rather than with curiosity or opportunistic viewpoint. What if variation in response to pasture or rangeland treatments was viewed as a potential source of solutions to problems, much like residual feed intake is in the exploration of efficiency? Provenza (1995) argues that an animal's diet while grazing pastures or rangelands reflects their ability to select from a smorgasbord of sedges, grasses, and forbs, and that much of that selection is learned (Provenza, 1995). He proposes that this learned behavior is based on aversion, which yields benefits like a balanced diet, and a reduction in the ingestion of toxic foods (Provenza, 1996). The fact that there is variation in diet selection, and that it is learned, provides fertile ground for research in the quest for optimization in forage based beef cattle production systems.

Micro-economics. If the goal of beef improvement is positive change in a trait of interest to beef cattle producers specifically, or the beef industry in general, then the application of the principles of economics should be applied. The basic micro-economic principle of marginality as related to technology in beef cattle production systems cannot be ignored (Dunn, 2004). The cost of producing more of anything is not fixed, but lies on a curve, referred to as a marginal cost curve. For example, the cost of producing each unit of a product is not equal. It decreases as the production function achieves efficiency but then increases as the point of diminishing returns is reached and surpassed. The cost of increasing the gene frequency of a trait falls on a marginal cost curve. When the cost of adding an additional unit exceeds its value, it is irrational to add more. Increasing the gene frequency of genes that affect a trait like marbling makes sense when the carcass premiums for choice versus select are large and exceeds the marginal cost. But consumer demand for beef is elastic, and carcass premiums reflect not only the elasticity of demand, but also of supply. Further, the elasticity of consumer demand for beef is much greater than the elasticity of the supply of beef, let alone for specific characteristics like marbling. This inelasticity of the supply of beef in general, and for specific traits in particular, is a function of the long production cycle associated with beef production and the relatively low hereditability and slow generation turnover associated with beef cattle genetics. A logical explanation of why the choice/select spread has narrowed in 2010 is because the protracted worldwide recession has caused a decline in consumer demand for choice beef in relation to its relatively inelastic supply.

If the principles of micro-economics are applied in a systems analysis of a trait like marbling, several key aspects need to be considered. First, the value of marbling would be determined or estimated in a dynamic economy, taking into account economic trends and the elasticity of demand for choice beef. Secondly, optimum levels of the frequency for genes associated with marbling would be established based upon the marginal cost of achieving each level. Thirdly, the marginal cost of alternatives like fetal programming or creep feeding would be determined. Finally, if the marginal cost of increasing marbling is below the projected return, a combination of technologies would be applied that keep the return on investment as high as possible.

Examples of System Thinking as Related to Beef Improvement. During the 37th Annual Research Symposium and Annual Meeting of the Beef Improvement Association, Dr. Bryan Melton challenged the beef cattle industry to include economics as part of multi trait selection indices and to follow those with economically weighted EPDs (Melton, 1995). While widely used in the pork and poultry industry, his 1995 challenge seemed novel to the struggling beef industry. Today, the major breed associations provide bioeconomic values based on economically weighted multi-trait selection indices to assist their members and customers in the genetic selection process. While not always transparent, they are an excellent example of solving the mystery of beef improvement in a thoughtful, multi-disciplinary, receiver dependent approach.

In 2002, Splan et al. (2002) published heritability estimates for weaning weight based on the records of 23,681 crossbred steers and heifers from the USDA-Meat Animal Research Center in Clay Center Nebraska to be 0.4 ± 0.02. Texts on beef cattle production and extension publications generally report that weaning weight is moderately heritable at 0.35 to 0.40. But is the heritability of weaning weight the same across all geographical locations? Could the environment in some locations be so extreme that it could reduce the heritability of this important trait? Although anecdotal, in 2008, John Genho analyzed the production records of over 20,000 Santa Gertrudis cattle from King Ranch, Kingsville, Texas. Using the Cornell Animal Model, he reported that the heritability estimate for weaning weight from these records to be 0.10 (Genho, 2008, Personal Communication). In terms of environmental conditions and nutritional availability, the subtropical environment in which these cattle were raised is extreme. Perhaps these animals from south Texas had a reduced opportunity to express their true genetic potential for weaning weight when compared to cattle raised in conditions that are more similar to those reported in the literature. Could this be true in other environments? If it is, it could have important economic implications for cattle producers from areas of outside the Midwest.

In conversation last winter Steve Radakovich, one of the early system thinkers in the beef industry as well as a longtime leader in the Beef Improvement Federation, posed a provocative question. “In beef cattle metabolism, maintenance energy is used for bodily function and repair. Since longevity requires the constant repair and maintenance of critical organ systems, and if efficiency is gained by lowering the portion of energy partitioned to maintenance, could we be selecting against longevity as we improve efficiency?” (Radakovich, 2010, Personal Communication)? This question is representative of the creative thought necessary to solve the complex challenges of beef improvement. It has at its core the fundamental principles of complex systems as outlined by Forrester (Sterman, 1998).

The pork and poultry industries have long been viewed as competition for beef. A general response of the cattle industry has been to find production systems that mimic theirs, and to find ways to compete with them from a feed efficiency basis. What would beef improvement look like if the environment was viewed not as a variable to be controlled, as it has been in the pork and poultry industries, but as a competitive advantage to exploit? Variation in wine is the backbone of the industry. Regional differences in fruits and vegetables are being promoted.

This question is easy to dismiss in an industry that is singularly focused, but is worthy of discussion in an industry willing to look outside the box.

Answers to the questions above, and many more, will challenge the very best scientists and thought leaders in beef cattle research and industry. But the primary question centers on the beef industry's willingness to ask them.

Conclusion

> *"I doubt if we stand a good chance of achieving understanding of the components, and of the interactions among them, as long as we insist on maintaining the comfort of our specialist or discipline zone. All indications to me are that we need more integrations of our disciplinary efforts both within and among beef cattle problem areas if we are to make the greatest contribution to developing technology for maximizing the amount of edible beef of a given quality per unit of resource use."*
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> Gregory (1972)

The debate about beef improvement shouldn't be centered on a validation of the past. The historic path chosen by the industry has achieved its goal of change. But the beef industry's serious and compelling problems lie in the future. The challenge for the Beef Improvement Federation at its 42nd Annual Research Symposium and Annual Meeting concerns the path it chooses for tomorrow. Will it continue as a "transmitter dependent" organization in search of puzzle pieces? Or will it become a "receiver dependent" organization that accepts Keith Gregory's challenge to break out of the "comfort of our specialist or discipline zone(s)" and expand its view as it unravels the mystery that is the complex system of beef production and improvement?

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