Introduction to Indexes

Robert L. (Bob) Weaber, Ph.D.
University of Missouri, Columbia, MO 65211

Why do we need indexes?

The complications of multiple-trait selection and animal breeding decisions may be best summarized by Dr. Lanoy N. Hazel in the opening paragraph of his landmark paper on the topic of selection indexes published in the journal *Genetics* in 1943:

> The idea of a yardstick or selection index for measuring the net merit of breeding animals is probably almost as old as the art of animal breeding itself. In practice several or many traits influence an animal's practical value, although they do so in varying degrees. The information regarding different traits may vary widely, some coming from an animal's relatives and some from the animal's own performance for traits which are expressed once or repeatedly during its lifetime....These factors make wise selection a complicated and uncertain procedure; in addition fluctuating, vague, and sometimes erroneous ideals often cause the improvement resulting from selection to be much less than could be achieved if these obstacles were overcome.

Hazel points to the complexities of selection of individuals when many traits are observed and when the 'information' or performance record of an individual and its ancestors, collateral relatives and progeny may vary considerably. Indeed, the overall net merit of the individual, considering several traits of economic importance, provides a superior selection criterion than other forms of selection including single trait selection and multiple trait selection via independent culling levels (Hazel and Lush, 1943).

Hazel's pioneering work solidified the idea of a breeding objective or goal using a quantitative method. The aggregate genotype described by Hazel was a linear function (selection index) of observations such that the observations of each trait were weighted by the relative economic value of that trait. The result was a single value for each animal that represented an objective valuation of the overall satisfaction with that animal. In production agriculture, our level of satisfaction with an animal or system is generally measured in profit. The selection index provided a natural connection between the net merit of an animal's genotype and its relationship with profit.

As beef producers, we know that more than one trait exhibited by beef cattle contribute to profit at the enterprise level. Clearly, a cow-calf producer that sells calves at weaning depends on more than just the average weaning weight of calves for profitability. Simple ranch accounting suggests that reproduction rate, calf survivability, cow maintenance feed costs, length of productive life and others influence the total pay weight of weaned calf produced and the cost required to produce that weight. Likewise, the producer that sells calves at harvest relies on more than just marbling score or quality grade to pay the bills. Reproductive rate of the cow herd, maintenance costs, longevity, not to mention carcass weight, are all factors affecting profitability. Thus, breeding objectives should include all the traits that are of economic relevance.

The original work by Hazel and later the work of Henderson (1951), who incorporated the use of EPD into selection indexes, stimulated a great deal of activity in the area of genetic prediction. Significant time and monetary resources have been devoted by producers, breed associations, beef improvement organizations, public sources, and academics to produce the sophisticated genetic predictions at our disposal today. However, comparatively little work has been devoted to full implementation of multiple-trait predictions into the multiple-trait prediction tools (Bourdon, 1998) envisioned by the originators. While the EPD produced today are of sufficient precision and accuracy, they are presented without context. Bourdon goes on to state that, "There is no easily accessible, objective way for breeders, particularly breeders in the beef and sheep industries where ownership is diverse and production environments vary a great deal, to use these predictions intelligently." Academic animal breeders are encouraged to solve this problem. The solution to the problem of intelligent use of multiple-trait EPD is to integrate genetic predictions with multiple-trait selection strategy usable on a large scale (Bourdon, 1998).

Index Basics

The idea of the selection index has seen a number of improvements since its conception over sixty years ago. In general, index construction begins with determination of the breeding objective or goal. Next, generate a list of the traits that affect attainment of the goal and then determine the relative economic importance of each trait in the list. The traits measured are then used to predict the economic merit of each animal available for selection as a parent. An overview of the construction of indexes is provided below.

In its simplest form, the selection index (Hazel, 1943) defines an animal's economic merit as a parent in terms of the function (often called the breeding objective):

$$H_i = a_1 BV_{i1} + a_2 BV_{i2} + \ldots + a_n BV_{in} ,$$

where,

H_i = the aggregate economic merit of an animal, *i*, as a parent,
a_j = the relative economic weight of trait *j*, $j = 1 \ldots n$, where n = the total number of traits
BV_{ij} = the breeding value of animal *i* for trait *j*.

Since the true breeding values of individuals are never known, predictions of genetic merit maybe substituted. Then, candidates are ranked on a prediction of (**H**) called (**I**), the *index value* defined as (Henderson, 1963):

$$I_i = a_1 EPD_{i1} + a_2 EPD_{i2} + \ldots + a_n EPD_{in} ,$$

where,

I_i = the predicted aggregate economic merit of an animal, *i*, as a parent,
a_j = the relative economic weight of trait *j*, $j = 1 \ldots n$, where n = the total number of traits
EPD_{ij} = the Expected Progeny Difference of animal *i* for trait *j*.

Henderson's inclusion of EPD in the selection index provided an efficient methodology for the incorporation of large amounts of pedigree and performance on relatives of selection candidates into the selection index. Further, the index is then unbiased as the genetic predictions themselves are unbiased since they are derived from Best Linear Unbiased Predictions (BLUP) procedures.

Genetic predictions for all traits included in the breeding objective are not available in many cases. In this case, a subset of traits is included in the index as suggested by Schneeberger et al. (1992):

$$I_i = b_1 EPD_{i1} + b_2 EPD_{i2} + \ldots + b_n EPD_{in} ,$$

where,

I_i = the predicted aggregate economic merit of an animal, *i*, as a parent,
b_j = the predicted relative economic weight of trait *j*, $j = 1 \ldots n$, where n = the total number of traits
EPD_{ij} = the Expected Progeny Difference of animal *i* for trait *j*.

A widely cited example of a selection index designed for the improvement in the efficiency of beef production was published by Dickerson et al. (1974). This index was formulated as:

$$I = YW - 3.2 * BW$$

where,

I = the predicted aggregate economic merit of an animal,
YW = 365 day yearling weight,
BW = Birth weight.

To investigate the response to selection based on an index, a selection study using the index proposed by Dickerson et al. (1974) and a randomly selected control line was under taken using a composite population of cattle at the USDA ARS Fort Keogh Livestock and Range Research Laboratory in Miles City, MT. Results of the study demonstrated that selection using the index produced little effect on maternal traits but produced significant improvement in the index and post-natal growth in spite of the antagonism faced when selecting for decreased birth weight (MacNeil, 2003).

Establish the breeding objective

The first step in development of a selection index is to clearly define what the goal of the genetic improvement is. A verbal description, rather than a mathematical one, may provide easy way to initiate the process. An example could be, 'Maximize profit from the sale of weaned calved produced on a extensively managed ranch in an arid environment where replacement females are retained and developed from the calf crop.' This statement of goals points out that maximization of profit (and only profit) is the objective of selection. Further, it suggests a few traits such as weaning weight, maternal traits, and heifer fertility that should be included in the objective.

Identify Economically Relevant Traits

A description of the breeding objective like the one above will help identify economically relevant traits, those traits that have a affect on profit. Some of these traits will be ones that impact revenue generation and others that typify the incurrence of costs. In cases where economically relevant traits can be identified, but a genetic prediction is not available, then indicator trait(s) with genetic predictors should be included in the breeding objective. Indicator trait EPD should not be included in the breeding objective if the economically relevant trait EPD is available as doing so decreases the accuracy of the index and subsequent selections (Golden et al., 2000).

Determine the Relative Economic Values

In many ways, the formation of the breeding objective and the listing of traits to be included in the index are much simpler tasks than computation of the relative economic values which are the weighting factors for traits in the index. The adoption and implementation of indexes of aggregate economic merit has been limited by the absence of economic values and, as such, the current genetic evaluation falls short of the grand vision developed over 60 years ago (Goldon et al., 2000).

Economic values or weights (the a's or b's in the above equations) reflect the change in profit when a trait is changed a single unit, holding all other traits in the list constant. One approach to obtain the relative economic values is to obtain the partial derivatives of the profit equation with respect to each trait in the objective, and the derivatives are evaluated at the mean value of all other traits. A profit equation is a single function designed to represent the relationship that exists between the animals' performance in economically relevant traits and firm level profit (Bourdon, 1998). MacNeil (1998) described the profit function as a highly aggregated simulation model.

Although much of the early literature surrounding selection indexes utilized only linear profit functions or breeding objectives, methods developed in the 1970s and 1980s included the ability to evaluate non-linear profit functions. The ability to consider non-linear profit functions was an important development as it addresses the issue of diminishing returns common in many biological and economic systems.

An alternative method for computation of economic weights is the use of bioeconomic simulation. A bioeconomic simulation model is a collection of a large number of equations (typically nonlinear) that simulates biological relationships, management systems, and determines profitability. The bioeconomic simulation is typically superior to the single profit equation methods in its precision predicting relative economic values. The improved precision is due to bioeconomic simulations higher degree of biological detail accounting for the 'convoluted' effects that changes in the genetic component of an animal's performance can have on profit (Bourdon, 1998). Further, Bourdon points out that despite the complexity and difficulty of parameterization of a large bioeconomic model, the model can provide a very informative and useful tool for both genetic selection decisions, but also exploration of alternative management strategies.

Generalized Indexes

Recently there's been a flurry of activity by researchers and breed associations to develop a variety indexes. A majority of these indexes are end-point or marketing point focused. These generalized indexes are applied on a breed-wide basis. Generalized indexes are appropriate whenever breeding objectives are consistent across large segments of an animal population. Bourdon (1998) cautions, however, that the usefulness of 'one-size-fits-all' indexes maybe questionable for species like beef cattle where production environments, management, mating systems, and marketing strategies vary considerably. The relative economic values appropriate for a specific operation and the industry average may be dramatically different. Use of inappropriate relative economic values will undoubtedly produce erroneous results. Additionally, operations that depart significantly from the parameter assumptions used in formation of generalized indexes are not likely to obtain satisfactory results. Even though this first implementation of indexes may not be extremely accurate, they do provide an educational tool and for many producers generalized indexes are an improvement over the implemented ad hoc selection method.

The Future of Selection

Since the generalizations made in formation of 'one-size-fits-all' indexes may lead to inappropriate decisions, development of site specific indexes becomes necessary. The customized index should be tailored to fit the specific economic, environmental, marketing and management constraints of an individual farm or ranch. The use of profit function derived index weights may provide the most approachable method for customization. Unfortunately, the level of aggregation utilized may lack the precision necessary for reliable site specific recommendations. Development of bioeconomic simulation software which is more precise and that is easy to parameterize and deploy appears to offer the best hope for implementation of multiple-trait selection technologies. Sire selection by simulation of the firm as suggested by Bourdon (1998) outlines a methodology for effective multiple-trait selection that goes beyond traditional selection indexes and provides for testing of look ahead mating system alternatives.

The speakers that follow will discuss a number of the current implementations of selection indexes and other selection tools. Their talks will give a view of the future may hold for multiple-trait selection decisions.

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