

## ESTIMATING FEED INTAKE OF BEEF CATTLE: MECHANISTIC MODEL DEVELOPMENT

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### INTRODUCTION

Mathematical models of animal functions have been developed in many ways. Models span the scale from simple regression equations relating static inputs and outputs, to interacting sets of differential equations simulating complex dynamic behavior, all for the same modeled system. Model form is dependent upon the purpose of the endeavor. In general, when description is the objective, less complicated models are preferred. That is, empirical relationships, linear equations and a few parameters are attributes of such models. Precision is achieved by using observed input-output relationships over the range of conditions to be used in subsequent predictions. When increased understanding of system behavior is the objective, more complete characterization of components and their interactions becomes necessary. Causal (mechanistic) relationships and nonlinear equations for a number of system components are found in such a model. Differential equations and numerical integration are included if the model is dynamic. Thus, the behavior of the system when challenged with a greater variety of inputs may be tested, and qualitatively accurate outcomes observed that are not intuitively obvious because of the complexity of the system.

One usually thinks of livestock producers or their advisors as users of the predictive, empirical models, and research scientists users of the more explanatory, mechanistic ones (France and Thornley, 1984). However, the possibility of combining the precision of the empirical models and the power of the mechanistic ones does exist, and can be exploited. In particular, one can add mechanistic elements to empirical models to add generality without losing precision. The mechanistic elements may be thought of as submodels in that they describe the behavior of the system at a lower or less aggregated level. Thus, attributes at one level are linked to those at a lower level so that those at the higher level may be predicted based on the underlying processes, or biology. This is in contrast to the empirical relationships connecting attributes, usually at a single level.

### CONCEPTUAL BASE

The above is best illustrated by describing models in relation to their level of aggregation (Figure 1). Mechanistic models use relationships at a lower level ( $i-1$ ) to explain system behavior at a higher, more aggregated level ( $i$ ). Within a level, relationships are defined as empirical. The two levels are linked by a process of analysis

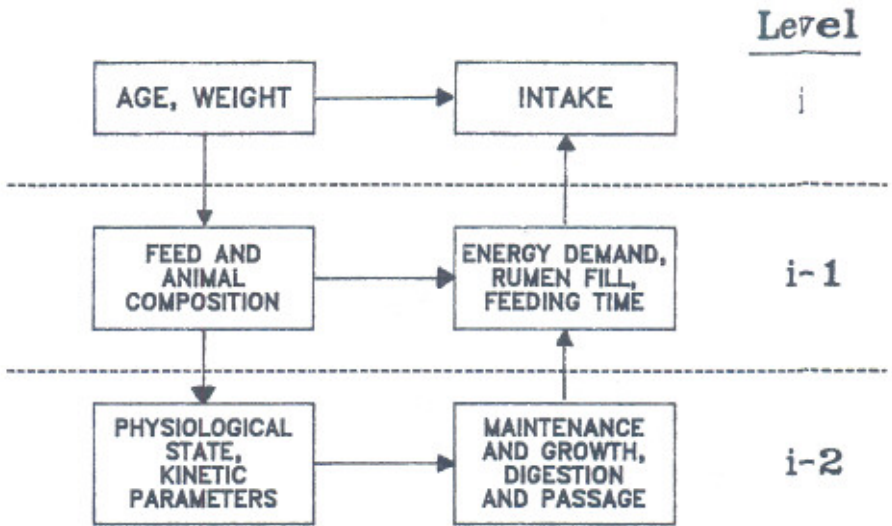


Figure 1. Levels of aggregation in the feed intake system

and resynthesis (France and Thornley, 1984). The i-1 level itself may consist of empirical relationships, or it may contain mechanistic elements itself which refer to the i-2 level. Thus, feed intake may be characterized by empirical equations containing terms at the whole animal level (i); by mechanistic equations incorporating effects of feed and animal composition on rumen fill and energy demand (i-1); or by even more complex relationships between physical characteristics of the feed and digestion dynamics (i-2).

If we consider the presently used empirical feed intake equations, there may be an infinite number of possibilities for improving their accuracy. However, the relationships between intake and other i level variables are only as good as the original data used to relate the variables. Extension to new circumstances, or application of a system with slightly different methods, may thus be severely limited. Further, results of new advances in nutritional knowledge are often impossible to explicitly incorporate into the systems. However, by including mechanistic elements representing underlying biological processes (i-1, i-2, etc.) in the system, modifications of the represented biological elements will be accounted for in the feed intake predictions.

Why, then, do we not routinely use mechanistic computer models to predict feed intake? The first reason is that they are not generally available; if one is available for a specific purpose, its portability is usually limited, like other computer models. Further, our understanding of the systems regulating feed intake is inadequate, and therefore the

necessary underlying mechanistic relationships have not been available for development of such models. Finally, good empirical models exist in some production situations (eg. feedlots) which provide precise estimation of animal intake.

#### MECHANISTIC MODELS FOR RESEARCH OR MANAGEMENT

Perhaps in time mechanistic models of feed intake may evolve into useful management tools. At that time, their primary use is no longer for research. That is, for hypothesis testing (research), a model used for increased understanding may possibly help us most when it is wrong and fails to correctly describe what is really occurring. It is at these points of failure that a mechanistic model suggests how to proceed in a research program by identifying our misrepresentation of some underlying biological relationship. An empirical model, when it is wrong, simply suggests that the form of the single level relationship is wrong for that particular situation in which it fails, giving no information on the underlying causes. For example, an empirical model of feedlot intake fails because incoming cattle of different age and bodyweight eat different amounts, even at a given bodyweight. An analysis of weight or age (level i) would most likely lead the researcher away from a more likely hypothesis that body composition affects energy demand (level i-1) suggested by a mechanistic approach. Of course, the above presupposes that proper model development and evaluation technique has been practiced. Therefore, the mechanistic approach has the potential to increase our understanding of the feed intake control system.

Similar approaches have added resolution to our estimates of animal performance in other areas. In particular, successful models have described growth and body composition changes (Oltjen et al., 1986), lactation (Baldwin, personal communication), rumen function (France et al., 1982), and to a limited extent, feed intake (Bywater et al., 1984).

#### LIMITATIONS OF MECHANISTIC MODELING

Several problems do arise in application of mechanistic modeling. It does require a broader view of other disciplines, particularly with regards to mathematics and statistics. Perhaps because of inadequate training in these disciplines and improper techniques, much poor work exists. Further, extravagant claims have been made for modeling, particularly for systems where data or knowledge simply does not exist to fully characterize a system. Obviously, these efforts are predisposed to failure. Evaluation has been a problem as well; the 'validation' procedures of traditional statistics are not as useful as sensitivity analysis. Finally, unclear objectives have led many to develop models with no clear purpose, often resulting in models with mixtures of unbalanced and poorly interacting components.

#### ADVANTAGES OF MECHANISTIC MODELING

It is the opinion of this author and others (Baldwin, 1976; Thornley and France, 1984) that a number of advantages may be gained by using the ideas associated with mechanistic modeling in a biological research program.

1. The requirement for mathematical completeness forces those concerned with building a model to examine the system objectively and consequently undertake a thorough and critical review of knowledge concerning the system. This helps pinpoint areas where knowledge is lacking, and might stimulate new ideas and experimental approaches.
2. Modeling may lead to less ad hoc experimentation, as models sometimes make it easier to design experiments to answer particular questions, or to discriminate between alternative mechanisms. It also enables the study of hypothesis where real-life experimentation would be either impossible, inordinately costly, or disruptive.
3. In a system with several components, a model provides a way of bringing together knowledge about the parts, to give a coherent view of the behavior of the whole system.
4. Data are becoming increasingly expensive to obtain and data collection more complicated; a model can sometimes make more complete use of data.
5. A mathematical model can provide a means by which research knowledge is made available in an easy-to-use form by the livestock producer.
6. The predictive power of a successful model may be used in many ways in research and management. For instance, a model can be used to indicate the answer to 'what if ...?' questions: What would be the consequences of doubling the particle breakdown rate of a forage on animal production? What would be the consequences of feeding low levels of high energy supplement to a grazing animal on forage consumption and gain?

#### SUMMARY

In this paper I have described the differences between an empirical and a mechanistic approach to mathematical modeling. Using less aggregated concepts, or the underlying biology, is the key idea of the mechanistic method. In conjunction with a research program, mechanistic modeling has many advantages, not the least of these is the complete and integrative view of the system imposed, yet with an appreciation for all the details. And, for predictive purposes, mechanistic elements in any system make it more general and allow some degree of extrapolation not possible with empirical equations.

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