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Modelling to support health programs in modern livestock farming

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Abstract

The application of herd health programs in livestock farming is rarely an all-or-nothing affair. Usually several control measures are available, but none is ideal. The use of models in optimizing the application of herd health programs is on the increase. Two broad categories of models have been reviewed: (1) statistical/epidemiological models used for direct evaluation of any program actually carried out (positive approach), and (2) economic models, used for predicting the profitability of specific measures or programs (normative approach). Priorities for further research in the field of animal-health economics are also discussed.

Introduction

Modern livestock farming is generally attended with an extended herd size and a narrowed income margin. Controlling the cost of production, therefore, is becoming more important. Improving animal health and fertility can play a major role in this context. Total losses caused by health and fertility problems in Dutch dairy cattle, for instance, have been estimated to average Dfl. 400 per cow per year. This is about 10 % of the gross production value or 40 to 50 % of income for a typical farmer. Differences between farms in these were found to be of the same magnitude (Dijkhuizen, 1983).

Current veterinary services to individual farms are changing from the so-called first-aid-practise or fire-brigade approach (Morris & Blood, 1969) into planned prevention and control programs. The application of such herd health programs is rarely an all-or-nothing affair. Usually several programs are available, each of them offering a different degree of protection. The basic principle for determining the optimal level of protection is the equimarginal principle: the input should be increased up to the level where the cost of an additional input equals the returns from the additional output. Increasing effort is made to apply this principle in the area of animal-health economics. In this paper some commonly used models are discussed.

Basic research approaches

Financial losses from diseases at the farm level can be attributed to one or more of the following three factors (Renkema & Dijkhuizen, 1984):
1. Less efficient production and more veterinary cost prior to disposal.
2. Reduced slaughter value and idle production factors at disposal.
3. Lost future income due to disposal.

Item 3 only occurs when animals have to be replaced before reaching their economic optimal age. The loss is the difference between (1) the income that a particular animal could earn during its remaining expected life, had the reason for replacement not presented itself – given normal probabilities of disposal due to other reasons – and (2) the expected average income of replacement animals with normal productive qualities and normal probabilities of disposal over the same period of time.

In order to determine the profitability of herd health programs, it is necessary to know the financial effects of diseases both in the presence and absence of the program. This is not a simple task because disease effects (1) are not always obvious and pronounced, (2) are influenced by other factors such as nutrition and housing, (3) have a temporal dimension which adds to the complexity of evaluating their impacts at different stages in time, and (4) often manifest themselves in a complex with other diseases (Ngategize & Kaneene, 1985).

Basically, two different research approaches are to be considered: a positive and a normative approach (James & Ellis, 1980; Renkema & Dijkhuizen, 1984). The positive approach can best be described as a direct evaluation of any health program actually carried out, using statistical/epidemiological models. For a sound analysis, data from both the 'with' and 'without' situation should be available. This may be realised in two ways: data from 'before' (b) and 'after' (a) application of the program, collected on farms participating in the program (P) as well as on comparable control farms (C). When available, these data make it possible to estimate the causal effects of the program more precisely, i.e. $(P_a - P_b) - (C_a - C_b)$, especially when particular herds with obvious health problems take part in the program. Such field experiments, however, are costly and time-consuming. Moreover, it is difficult to collect data from control farms without interfering with the program. This may help explain why so few such experiments have been carried out whereas so many could be done considering all the possible combinations of diseases, control measures, animal species, farm and price conditions.

More attention has been paid to the normative approach, which is intended to predict the effects of a certain health program based on existing knowledge about the veterinary aspects of the diseases involved and about the farms which are supposed to apply the program. This knowledge may be derived from pure veterinary research, but also from field data. In such an approach it is recommendable to construct a formal mathematical model which describes the disease and its physical and economic effects, enabling a simulation of the effects of various preventive and control measures. Modelling necessitates specification of the required relations in detail, often revealing lacunae in knowledge. A sensitivity analysis can easily be carried out to indicate the economic importance of increased knowledge, which may contribute to decisions on priorities in further research. Special attention has to be paid to the correspondence between model and reality in order to obtain meaningful results for real-world situations.

According to Ngategize & Kaneene (1985) the specific models to be reviewed in this paper are discussed under two headings: statistical/epidemiological models and economic models. Such a distinction more or less coincides with field data analysis (positive approach) and computer modelling (normative approach), respectively. Under each category the most common models are described. Some illustrative literature is presented for further reference.

Statistical/epidemiological models

Simple group comparison is probably the most widely used method in field data analysis, especially for a first screening of data. Herds or animals are divided into groups based on one key-variable of interest, e.g. with or without herd health programs. Results are easy to read, but should be interpreted carefully because of possible confounding problems, occurring when there are differences in relevant factors other than the key-variable.

Factor analysis refers to a variety of statistical techniques whose common objective is to represent a large set of variables in terms of a much smaller number of mutually independent, hypothetical variables ('factors'). Usually it is used when it is not possible to specify beforehand a set of explanatory variables to describe the variation in the variable of interest. Factor analysis is an expedient way of ascertaining the minimum number of linear factors that can account for the covariation among the observed variables. When doing factor analysis, three basic steps have to be carried out: (1) preparing the relevant covariance matrix, (2) extracting initial factors and (3) rotating to a terminal solution. Sol & Renkema (1984) used this method in analysing the profitability of a broad dairy herd health program in the Netherlands. The sensitivity of the method was improved by describing the final situation for each variable in two values: the pre-program value and its change during the program. Nevertheless, because of other disturbing influences, they did not succeed in relating the positive effect of the program on individual parameters to the partial increase in income caused by it. For this reason a combined use of positive and normative model calculations was recommended.

Discriminant analysis is used to distinguish statistically between groups of cases. Discriminating variables on which the groups are expected to differ have to be selected beforehand. The mathematical objective then is to weigh and linearly combine the discriminating variables in some fashion so that the groups are made as distinct as possible. Discriminant functions are of the form: $D = \Sigma d_i Z_i$ $(1 \leqslant i \leqslant n)$, where D = the score of the discriminant function, d_i = weighing coefficients and Z_i = standardized values of the discrimination variables $(1 \leqslant i \leqslant n)$ used in the analysis. Dohoo & Martin (1984) used discriminant analysis for the simultaneous evaluation of several production parameters and previous disease history as determinants of disease in subsequent lactations. Vandegraaff (1980) used the same procedure to identify the most important environmental and host factors contributing to discriminate between affected and non-affected dairy farms with respect to salmonellosis.

Regression analysis is a body of statistical methods for quantifying the relationship between one or more explanatory variables and a dependent variable. The number of explanatory variables as well as the expected nature of the statistical relationship have to be specified beforehand. In ordinary regression analysis, both the dependent and the explanatory variables are quantitative and continuous. In case of qualitative and discrete variables, however, dummy variables having the value of unity or zero can be incorporated. Regression analysis has been and remains an important statistical tool in a wide range of disciplines. Olds et al. (1979) used it in studying the effects of days open on the economic aspects of current lactation in dairy cattle. An interesting application was made by Hunt McCauley (1974), who specified a production function to measure the relative contribution of various farm resources to US dairy farm income. An extra dollar spent on veterinary services was estimated to make a positive contribution to income of $2.96.

Path analysis can be viewed as a modification of regression analysis, which makes it possible to interpret causal relationship of complex disease situations. It has been used more often in disciplines such as sociology and psychology than in economics or epidemiological analysis. The method attemps to decompose and interpret relationships among a set of variables by assuming that a (weak) causal order among the variables is known. Paths of these relationships can then be built, based on observations and knowledge of the system over time. These paths are tested to ascertain their significance as in the usual regression models. Erb et al. (1985) have used path analysis models extensively in investigating the causes and effects of different diseases in dairy cattle.

Economic models

Partial budgeting is simply a quantification of the economic consequences of a specific change in farm procedure, e.g. a herd health program. A partial budget is typically made up of four sections: (1) additional revenue realized from the change, (2) reduced costs as a result of the change, (3) revenue foregone as a consequence of the change, and (4) extra costs incurred due to the implementation of the change. The change should be adopted if the sum of (1) and (2) is greater than that of (3) and (4). Special attention should be paid to the question if it fits into the total farm strategy. In animal-health economics, applications of this method include analysis of fertility problems and mastitis in dairy cattle (Esslemont, 1982; Zeddies, 1982; Dijkhuizen et al., 1985).

Cost benefit analysis is a procedure for determining the profitability of programs over an extended period of time, i.e. sufficiently long so that addition of an extra year does not materially influence the comparative ranking. Future costs and benefits are 'discounted' to make amounts occurring at different points in time completely comparable. Inflation should be excluded from the interest rate when it is excluded from the other prices as well. Results of a cost-benefit analysis may be expressed in the form of the net present value (discounted net benefits), the benefit-cost ratio (ratio of present value of the gross benefit to present value of the costs incurred) and the internal rate of return (the interest rate which would have to be charged to reduce the net present value to zero). One variant of cost-benefit analysis is cost-effectiveness, to be used when the expected benefits are excessively difficult to quantify, and producing the desired result at minimum discounted cost. Both the cost-benefit and cost-effectiveness approach have been most extensively used in nation-wide control programs competing for the same financial funds, e.g. programs for swine fever eradication in the EC (Ellis et al., 1977).

Decision analysis is defined as any framework or strategy for handling complex decisions so that they can be more readily evaluated by the human mind (Ngategize et al., 1986). One such framework becoming increasingly useful in the veterinary field, is a decision tree (Fetrow et al., 1985). In a decision tree, choices such as whether or not to treat are presented by squares called decision nodes. Chance events, such as response to treatment, are presented by circles called chance nodes. The lines, or branches, following each decision node must be exhaustive, that is, they must include all possible outcomes, and the outcomes must be mutually exclusive. Decisions are usually based on criteria such as minimax, maximax, expected monetary value or expected utility. In animal health management, decision-tree analysis has been used in poultry health program design (Carpenter, 1980), in deciding whether or not to treat cows with left-sided abomasal displacement (Breukink & Dijkhuizen, 1982) and in assessing the economic usefulness of vaccination against porcine parvovirus (Parson et al., 1986).

Linear programming is a technique for determining the optimal allocation of resources to competing activities. The following requirements have to be met: (1) specification of an objective function, i.e. a quantity, usually monetary, to be maximized or minimized, (2) identification of the different activities competing for resources, (3) identification and quantification of the resource constraints, and (4) knowledge of input/output coefficients. The technique assumes linearity in production and divisibility of resources, but variants have been developed to handle situations where these assumptions have been violated (e.g. integer and N-stage programming). Linear programming has been used most often in determining the optimal combination of farm enterprises. Application in animal health is still in its early stages (Carpenter & Howitt, 1980).

Dynamic programming is a general class of mathematical techniques that has no standard formulation. It is concerned with processes which involve a sequence of decisions over a given period of time, called the planning horizon. Optimization generally starts at the end of this planning horizon and moves backwards in time to the present stage. At each stage the optimal decision is determined for all combinations of the state variables, which specify the state of the process (e.g. age and production in case of livestock). Dynamic programming places no restrictions on the functions used to specify the structure of the system. Furthermore it is possible to alter parameter values over time, offering the opportunity to include, for instance, seasonality and continuous genetic improvement. In the field of animal-health economics, dynamic programming has been most extensively used in culling decisions in dairy cattle (Kristensen & Ostergaard, 1982; Van Arendonk, 1985) and swine (Huirne et al., 1987).

Markov chains are used to model the evolution of systems or processes over repeated trials or successive time periods. In animal-health economics, Markov chains are usually simplified to make computations where the units under consideration (animals or herds) can exist under a number of mutually exclusive states, and probabilities can be specified for chances of the units transferring from one state to another (James, 1977). This requires knowledge of the transition probabilities and the number of animals or herds in each state. A crucial assumption is that the transition probabilities are stationary. Appropriate states to be considered in case of contagious diseases are susceptible, affected, immune and removed. Van Arendonk & Renkema (1983) applied the method to study the spread of TGE in swine breeding herds.

Systems simulation represents an attempt to emulate real-life conditions using simple models over time. The fundamental concept underlying the structure of such models is that individual animals within a herd are 'moved' forward through time, modifying the status of each according to the outcome of various events and management decisions. These events and effects of decisions can be characterized in a stochastic manner, i.e. as random samples on appropriate probability distributions rather than as fixed values. To determine whether an animal becomes pregnant after a particular mating, for instance, the computer draws a random number from a uniform distribution between 0 and 1. If the random number is greater than a predetermined long-term probability of say 0.60, then the animal is considered not to have conceived. Such a procedure produces a spread in results over a series of calculations, which better reflects normal biological variability. Dijkhuizen et al. (1986b) developed a stochastic dairy herd simulation model, focused on production, reproduction, culling and income. Marsh (1986) developed a comparable model running on a microcomputer. In this model, a generic livestock generator was developed to be used as a starting point in modelling the reproductive cycle of a number of livestock species (a so-called skeleton model).

Discussion

To improve quantitative understanding of the profitability of herd health measures at the farm level, a wide range of models is available, as shown in this paper. The choice of a model will depend on a number of factors including: (1) the nature of the disease, (2) the problem under consideration, (3) the resources available, such as time, money and analytical tools, and (4) the availability of the necessary data and information about the problems (Ngategize & Kaneene, 1985). Preferably, the structure of any model should allow modification of input variables, making it suitable for situations on individual farms in different countries. Usefulness for day-to-day management decisions is improved when models can be run on microcomputers. Recent experiences with such models have been positive (Dijkhuizen et al., 1986a; Marsh, 1986).

Model calculations in animal-health economics often suffer from a serious lack of accurate data. This applies in particular to the case history of individual animals or flocks, and might help explain why so few model calculations have been done for pigs and poultry. During the last few years much effort has been put into designing and implementing integrated veterinary, zootechnical and economic record keeping systems (Noordhuizen, 1984). In the future, systematic epidemiological and economic analyses of these data-bases should be given high priority. A basic question is whether – and, if so, which – standards are available to express the frequency and seriousness of the various diseases under field conditions. Further research in this field is necessary and can be of great practical value. In this way a valuable interaction between economic research on the one hand and veterinary and zootechnical research on the other is possible. Model calculations may be used to quantify the significance of gaps in veterinary and zootechnical knowledge, while knowledge obtained from this technical research increases the reality of economic models. This interaction is fundamental to the study of diseases and disease control at the farm level.

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