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Modelling to support animal health control

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ABSTRACT

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Animal Health Economics is a relatively new subject, being developed to provide a quantitative insight into the economic effect of disease and disease control in livestock. Research in this field is focussed on both the further development of a more solid scientific framework of concepts and methods and its applications in quantitative model calculations. Three issues are especially of interest: (a) the losses of disease, (b) the profitability of preventive measures, and (c) the replacement decision of individual affected animals. All three issues concern complex problems, which have to be studied under imperfect veterinary knowledge and under a high degree of uncertainty. In this paper the basic economic framework and its applications in the underlying field are discussed and illustrated.

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. Decisions concerning animal health, fertility and culling play a major role in this context. Total losses related to these aspects 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 and 40–50% of income for a typical farmer. Differences between farms were found to be of the same magnitude (Dijkhuizen, 1983).

Current veterinary services to individual farms are changing from the so-called first-aid practice or fire-brigade approach to planned prevention and control programs (Howe and McInerney, 1987). The application of such herd health programs is rarely an all-or-nothing affair. Usually, several programs are available, each offering a different degree of protection. From

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an economic point of view, the input should be increased up to the level where the cost of an additional input equals the returns from the additional output. Increasing modelling effort is made to apply this principle in the area of animal health economics.

The quantitative insight into the effect of diseases and disease control gained in this way can be used for (Renkema and Dijkhuizen, 1984): (a) assistance in indicating the lines on which veterinary and zootechnical research should develop by providing economic criteria, (b) broadening the basis for decisions when a choice must be made from alternative preventive and control strategies, and (c) supporting the livestock owner's policy with respect to animal production and animal health.

In this paper the basic economic framework and its applications will be discussed and illustrated.

ECONOMIC FRAMEWORK OF LIVESTOCK DISEASE

The losses caused by animal disease are determined to a large extent by a combination of three factors: the form of disease, the animal species, and the economic level involved.

Disease

From the risk point of view, and because of the economic effects of disease, a distinction should be made between:

- Diseases prevailing in the area under consideration, but whose incidences vary from farm to farm and about which the individual livestock owner can do very much to control them (so-called enzootic diseases).
- Contagious animal diseases, rarely occurring in a certain area, which require regional and/or national control measures (so-called epizootic diseases). When occurring, such diseases usually affect large number of animals. In major exporting countries, such as the Netherlands, it is important whether or not an epizootic outbreak leads to foreign trade restrictions.

Animal species

The effect of the losses on a certain animal species is especially influenced by the normal ratio between earned income and gross production value. In pig and poultry fattening, a 1% rise in cost price has much more impact on farmers' income than it would have in the dairy sector. For Dutch conditions, for instance, income decreases by about 15% in the former case and 5% in the latter.

TABLE 1

Losses due to animal diseases, considered for different economic levels

Economic level	Form of disease		
	Diseases generally present, through varying in degree per farm (A)	Incidental outbreaks of contagious animal diseases on a national or regional scale	
		(B1) Foreign trade restrictions	(B2) No restrictions to foreign trade
(1) Farm (individual producer)	Direct relation between loss and degree of occurrence of the disease per farm Particularly in pig- and poultry-farming, great effect on income	Large incidental loss, even if the farm is not affected by the disease Possible compensation for destroyed animals	Great loss on the affected farms (possible compensation for destroyed animals); advantage for farms not affected
(2) Sector (collective stock farmers)	Loss, insofar as the price does not adapt itself In the EEC as a whole, scarcely any relation between level of disease and income of stock farmers, on account of price adaptation	Spectacular loss, particularly in the case of export products, resulting from dropping prices due to failing demand	Moderate loss (depending on possible compensations and on degree of price adaptation)
(3) Supply- and processing industries; service and trade [a]	Pro memoria	Pro memoria	Pro memoria
(4) Consumer	Loss due to higher prices	Incidental advantage	Slight loss
(5) National economy	Loss due to inefficient use of resources	Disadvantage considerably less than loss collective stock farmers (2.B1)	Disadvantage can be greater than loss to collective stock farmers (2.B2) But loss 5.B1 probably greater than 5.B2

[a] This category has only been included pro memoria. Besides, it has been assumed for convenience sake that price changes are passed on to the consumer quickly and completely.

Economic level involved

The economic effects of animal diseases can be considered on different economic levels, e.g. for the individual farmer, the joint livestock owners, the other economic levels of the industry, the consumers and the national economy. The potential economic effects vary considerably across the different levels, as illustrated in Table 1.

When reading Table 1 it should be considered how the market price realized for the animal products reacts in the different cases. In the case of column A, supply and demand force prices to move over time with the average disease level. Thus the loss is transferred to the consumers, and conversely it is the consumer who benefits from improved animal health. In a sufficiently large market such as the EEC there is hardly any relation between the extent and seriousness of these diseases and the average income of the joint livestock owners. For the individual farmer this linkage does exist, however. The farm in question may suffer more (or less) from disease than is compensated by the average 'disease margin' included in the market price. To a lesser extent this also applies to a group of livestock owners.

If an epizootic outbreak occurs without leading to foreign trade restrictions (Table 1, column B2), the market prices may temporarily rise a little, dependent on the spread and duration of the outbreak. If exports are restricted, however (Table 1, column B1), prices in highly exporting countries will drop substantially due to an oversupply of the domestic market. This fall in price cause losses which may largely exceed the direct losses due to mortality, for instance. Unaffected farms also suffer from this drop in prices.

The national economy suffers a loss by animal diseases, because resources are being used less efficiently. Additional resources are required (e.g. labour and imported feed stuff) that could have been employed alternatively. Income transfers between consumers and producers are not relevant to the assessment of national economic losses.

DECISIONS IN ANIMAL HEALTH CONTROL

Determining the economic impact of animal diseases is not a simple task, because their effects (a) are not always obvious and pronounced, (b) are influenced by other factors such as nutrition and housing, (c) have a temporal dimension, and (d) often manifest themselves in a complex with other diseases (Ngategize and Kaneene, 1985).

Quantification of loss elements is not only important for a description of the actual situation, but also and more especially in so far as it can help to answer two interrelated sets of questions:

(1) How to limit the loss as much as possible if the disease does occur: either by further treatment or by replacement of affected animals?
(2) In what way(s) and to what extent can the risk of occurrence of the disease in question be diminished, how much loss is to be avoided and what effort and cost are required?

Both questions concern complex problems, which have to be studied with imperfect veterinary knowledge and under a high degree of uncertainty.

Basically, two different research approaches are applied to deal with these questions, a positive and a normative approach (James and Ellis, 1980; Renkema and Dijkhuizen, 1984). The positive approach can best be described as a direct evaluation of field data, using statistical/epidemiological models. Most extensive applications have been described in analysing the effects of preventive herd health programs (Sol and Renkema, 1984). 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 comparable control farms (C). When available, these data make it possible to estimate the causal effects of the program more precisely, i.e. $(P_a - P_b) - (C_a - C_b)$. Such field experiments are costly, however, and time-consuming. Moreover, it is difficult to collect data from control farms without interfering with the program. This may help explain why relatively 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 work has been done on the normative approach, which is intended to generate results by the method of system modelling (Korver and Van Arendonk, 1987), enabling a simulation of the effects of various management decisions and control strategies. System 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.

COMPUTER MODELLING IN ANIMAL HEALTH ECONOMICS: AN OVERVIEW OF RELEVANT TECHNIQUES AND APPLICATIONS

Ngategize and Kaneene (1985) previously reviewed different models in animal health economics under two headings: statistical/epidemiological models and economic models. Such a distinction more or less coincides with field data analysis (positive approach) and system modelling (normative

approach). The most common modelling techniques in the underlying field will now be described briefly. Some illustrative literature is presented for further reference.

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. 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). The cost–benefit approach has been most extensively used in nationwide 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. Change events, such as response to treatment, are presented by circles called change 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.

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 (Van Arendonk, 1985) and swine (Huirne et al., 1988).

Factor analysis refers to a variety of statistical technique 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. Sol and 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, they did not succeed in relating the positive effect of the program on individual parameters to the partial increase in income caused by it, because of other disturbing influences. For this reason a combined use of positive and normative model calculations was recommended.

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 changes 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. Appropriate states to be considered in the case of contagious diseases are susceptible, affected, immune and removed.

Path analysis can be viewed as a modification of regression analysis, which makes it possible to interpret causal relationships of complex disease situations. The method attempts to breakdown 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.

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. Such a procedure produces a spread in results over a series of calculations, which better reflects normal biological variability. Dijkhuizen et al. (1987) developed a stochastic dairy herd simulation model, focused on production, reproduction, culling and income. Marsh (1986) developed a comparable model running on a personal computer. 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).

STOCHASTIC SIMULATION MODELLING FOR ON-FARM DECISION SUPPORT

The decision-making process as such is commonly considered to include five stages: (1) recognizing the problem, (2) developing alternative solutions, (3) making a choice among these alternatives, (4) implementing the decision, and (5) evaluating the results (Boehlje and Eidman, 1984). Current management information systems in Dutch livestock farming are still restricted to data registration and analysis, which especially support stage 1 and partly stage 2. The attractiveness of these systems will considerably be increased if modelling tools can be incorporated to support the development of alternative solutions (stage 2) and the choice among the alternatives (stage 3) more directly. Animal health management is an outstanding area to experiment in designing such an integrated system, especially with respect to the day-to-day decisions on treatment and culling of individual animals.

To gain experience in the potential role of on-farm modelling, a stochastic simulation model was developed focused on day-to-day dairy-cow management (Dijkhuizen et al., 1987). In this model, each stimulated herd consists of a fixed number of up to 100 cows (with additional young stock), individually generated according to a set of predetermined herd characteristics. A simplified flowchart of the model structure is presented in Fig. 1. After an initial herd has been generated (year 0), changes in the herd can be followed at 20-day intervals over 15 years. The first 5 years are used to stabilize the initial situation; the next 10 years concern the experimental period in which different management issues can be compared. For each alternative, 20 runs of calculations are carried out to obtain statistically reliable results. Of the events necessary to calculate the economic results per individual cow and per herd, milk receipts, reproductive performance and involuntary disposal enter the model in a stochastic manner. The other

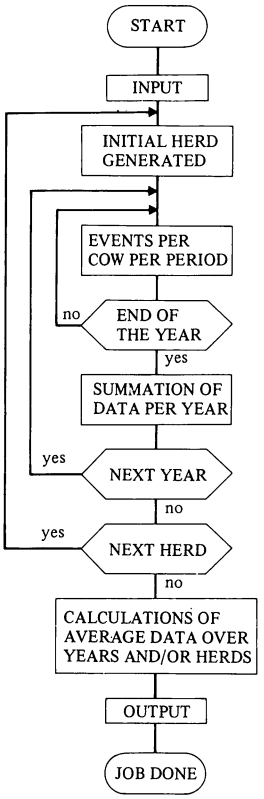

Fig. 1. Flowchart of the research version of the simulation model.

income factors are simulated deterministically, i.e. feed intake, live body weight, young stock rearing and prices.

To give an overview of the models' behaviour and potential, some results are summarized in Table 2. First a basic situation is described, based on input data representing typical Dutch farms with Black-and-White cows. Subsequently, the influence of deviations in dairy cow management issues is presented. Only one issue is changed at a time. These deviations as well as their effects are presented in absolute terms rather than as percentages of the initial situation. Deviations in both the calving rate after first service and the oestrus detection rate have a relatively small effect on income: 2–3% of net return to labour and management. Their effects on fertility parameters are much larger, and are quite similar except the effect on Fertility Status, which is affected much more by differences in calving rate after first service. This influences not only the number of open days, but also the pregnancy rate after first service and the number of breedings per conception, which is not necessarily the case with changes in oestrus detection. Although included in

TABLE 2

Economic impact of different management issues in dairy herds

	Basic	Deviations				
Calving rate after 1st service (%)	60	−20	+20			
Oestrus detection rate (%)	70			−20	+20	
Breeding and culling policy [a]	A					B
305-day production						
kg milk	5943	−31	−6	+1	−10	−613 *
% fat	4.15	+0.03	−	+0.02	−	+0.06
% protein	3.33	+0.02	−	+0.02	−	+0.02
kg milk per average cow present	5965	−78 *	+62 *	−71 *	+56 *	−206 *
Calving interval						
herd average (days)	378	+12 *	−9 *	+11 *	−8 *	−27 *
% cows ≥ 410 days	17	+10 *	−8 *	+10 *	−6 *	−17 *
Fertility Status [b]	63	−26 *	+23 *	−6 *	+6 *	+68 *
Annual culling rate (%)						
production and reproduction failure	7	+8 *	−3 *	+3 *	−2 *	+45 *
total	22	+6 *	−3 *	+2 *	−2 *	+42 *
Net return to labour and management (Dfl. per cow per year)	1210	−35 *	+34 *	−25 *	+28 *	−282 *

* $P < 0.01$.

[a] Policy A: strategic breeding, i.e. cows with a relative production level of 80%, no breeding at all; 80–90%, no breeding beyond 160 days after calving; ⩾ 90%, no breeding beyond 240 days. Policy B: no breeding beyond 80 days after calving, irrespective of the cow's productive capacity.

[b] Fertility Status = pregnancy rate after first service/number of breedings per conception − (interval calving to conception in days −125).

modern fertility record-keeping systems, Fertility Status, therefore, seems to have a limited value as economic indicator. In this context, differences within milk-yield parameters are also notable. The 305-day milk production is hardly influenced by changes in either factor, while the production per average cow present in the herd is significantly influenced. The latter parameter takes full account of the increasing number of days with minor or no production if calving interval increases and, so, is a better economic indicator than the commonly used and widely available 305-day milk-production parameter.

Breeding and culling policies have a much larger influence on income, but the policies considered are more extreme. The results in Table 2 show a strong decrease in income if the maximum allowable calving interval is reduced (Policy B), despite the favourable effect on the length of the calving interval of the herd. The advantage of a shorter calving interval is out-

weighed by the negative effects of increased herd turnover and replacement. A shorter calving interval, therefore, should be achieved by improved herd fertility management rather than by increased culling of cows which fail to conceive.

By entering farm-specific data into the model, it can be used to analyse alternative strategies for existing dairy herds. Research is underway to supply this kind of management-supporting model on a routine scale, suitable for running on personal computers. Recent experience in modelling dairy-cow and sow-management issues in this way was positive (Dijkhuizen et al., 1986; Marsh et al., 1987).

EPIDEMIOLOGICAL AND ECONOMIC SIMULATION OF FOOT- AND MOUTH DISEASE CONTROL STRATEGIES

Foot-and-Mouth disease (FMD) is considered as one of the most contagious of all animal diseases. The Netherlands is among those countries where the disease takes a sporadic form. For almost 30 years the national cattle herd has been vaccinated annually, and in that time the number of outbreaks reduced significantly. Recently, a discussion was going on whether continuation of prophylactic vaccination is economically worthwhile. To structure and support this discussion, a computer model was created within an electronic spreadsheet program on the personal computer (Dijkhuizen, 1989). The model runs with Dutch default values, but these can easily be modified to suit different conditions and countries, making it a flexible tool for real-life decision making.

The epidemiological routine of the model determines the spread of the disease after a primary outbreak. For that, a State-Transition approach is used, developed from a Markov chain model, making it possible to examine a variety of control strategies. Herds are considered to be in one of four mutually exclusive 'states': susceptible, infectious, immune or removed. Each week, the probability of every transition is calculated and the proportion of herds in each state during the next week is thus derived. The probability of a susceptible herd becoming infected (p_i) in a particular week (j) is assumed to be a function of the fraction infectious herds (f_i) in the previous week and the dissemination rate (DR):

$$p_i(j) = 1 - e**(-\mathrm{DR}(j-1)*f_i(j-1))$$

The dissemination rate (DR) represents the average number of herds to which agent is delivered by each infected herd. A working-group of Dutch FMD experts was installed to provide the necessary default values for all input variables.

TABLE 3

Summary of the epidemiological results in case of an outbreak

Control strategy	Weeks with outbreaks	Out-breaks	Herds removed
I Vaccinated cattle population			
a stamping out affected herds	7	21	21
b1 Ia, plus effective ring vaccination	5	16	16
b2 Ia, plus non-effective ring vaccination	5	17	17
II Non-vaccinated population			
a stamping out affected herds	29	712	712
b IIa, plus stamping out contact herds	8	59	140
c1 IIa, plus effective ring vaccination	5	134	134
c2 IIa, plus non-effective ring vaccination	8	170	170

Decisions of FMD control strategies reach beyond the scope of the individual farmer, making it obvious to analyze their economics on the national level. No algorithm is available, however, to model the indirect losses of export bans. Size and duration of such bans are usually dependent on political decisions as well, making it too arbitrary to predict the losses within each of the control strategies quantitatively. Expected differences in risk for export bans, therefore, have to be included, subjectively, in the final stage of the decision-making process.

By far the highest number of secondary outbreaks occur, as would be expected, in a non-vaccinated population with stamping out of the affected herds as the only control strategy (Table 3). In total, the outbreaks even then persist for over 6 months. Routine prophylactic vaccination is not necessarily the only remedy against such a dramatic spread of the disease, as shown in Table 3. The total number of outbreaks and the length of time in which they occur can also considerably be reduced by stamping-out the at-risk contact herds as well. It is doubtful, however, if public opinion would allow slaughtering animals of so many herds without clinical signs of the disease. On the other hand, the total number of removed herds hardly exceeds that in case of the strategy in which stamping out of the affected herds is combined with an effective ring vaccination. The number of secondary outbreaks is by far most reduced when the cattle population is vaccinated routinely. The most favourable epidemiological results, then, are obtained under the strategy currently being applied in the Netherlands, i.e. stamping out affected herds in combination with ring vaccination if outbreaks do occur.

The calculated direct losses under each of the strategies are summarized in Table 4. In the case of the most favourable situation regarding the

TABLE 4

Summary of the direct costs on a yearly base (Dfl. *1000)

Control strategy	Most favourable situation	Most likely situation	Most unfavourable situation
I Vaccinated cattle population			
a stamping out affected herds	24076	24897	25718
b1 Ia, plus effective ring vaccin.	24076	24814	25552
b2 Ia, plus non-effective ring vaccin.	24076	24999	25922
II Non-vaccinated population			
a stamping out affected herds	0	16154	64617
b IIa, plus stamping out contact herds	0	3182	12729
c1 IIa, plus effective ring vaccin.	0	3124	12497
c2 IIa, plus non-effective ring vaccin.	0	4 004	16017

number of primary outbreaks (0 within 10 years), routine vaccination of the cattle population, of course, is far from profitable, as shown in Table 4. But also in the most likely situation, annual costs are lowest in a non-vaccinated population, even with stamping-out of the affected herds as the only strategy. It is under the latter strategy that costs rise by far the highest in the case of the most unfavourable situation, considering the expected number of primary outbreaks (four within 10 years). The other strategies, however, still provide the best economic results in the case of a non-vaccinated population. Even when comparing the direct costs in the most favourable situation for a vaccinated cattle population on the one hand, and in the most unfavourable situation for a non-vaccinated population on the other, routine vaccination is still the less-profitable choice. This favouring conclusion for a non-vaccinated population in the Netherlands is barely influenced by more pessimistic values for the major uncertain input factors, and not likely to be outranged by indirect costs due to an increased risk for export bans. Further research is underway, however, to model the extent of these indirect losses more precisely.

DISCUSSION

Outbreaks of contagious diseases are properly feared, especially in major exporting countries. Current control strategies differ between countries on (a) whether or not routine vaccination is applied to prevent this type of disease, and (b) what eradication measures are taken if an outbreak does occur, e.g. stamping-out infected herds, ring vaccination, and animal movement standstills. Decisions on what strategy is best to apply are highly subject to uncertain conditions, especially with respect to the risk of primary

outbreaks and foreign trade restrictions. To make more economically sound decisions, therefore, an integrated modelling approach is required that simulates (a) the epidemiology of the disease, (b) the direct cost of prevention and eradication, and (c) the indirect effects due to export bans. For that, a further integration of the basic principles of Welfare Economics – considering measurement and weighing of potential effects on producers' income, consumers' income and government's budget – into Animal Health Economics is necessary.

At the farm level, management decisions have more to deal with health and fertility problems that are generally present but vary greatly in degree and frequency and severity across farms. Planned veterinary services to control and prevent this type of problem increasingly become an input factor to improve productivity, interacting with other input factors and competing for the same scarce resources. Optimizing the farmer's overall resource allocation, therefore, requires a quantitative insight into the relationship between veterinary service expense, animal health status and farm income. Research to specify this relationship has mainly been carried out through system simulation. More research is desired to make these modelling results better applicable for actual on-farm decision support. Especially when combined with expert system features and integrated in management information systems, it is possible (a) to generate results tailored to individual circumstances, (b) to simplify data input, and (c) to add relevant heuristic information not yet included in the algorithms (Huirne and Dijkhuizen, 1988; King and Dijkhuizen, 1988).

Field data analyses to confirm the promising modelling results have only been done sporadically, and not in much detail, mainly because of a lack of appropriate data. In recent 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. In this way a valuable interaction between system modelling and field-data analysis is possible. System modelling may be used to quantify the significance gaps in veterinary knowledge, while knowledge obtained from field-data research increases the reality of economic models. This interaction is fundamental to the study of disease and disease control.

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