Animal Health Economics

principles and applications

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Contents

Advanced methods of economic analysis

Preface

Animal Health Economics is a relatively new discipline, which is progressively developing a solid framework of concepts, procedures and data to support the decision-making process in optimizing animal health management. Research in this field primarily deals with three interrelated aspects: (1) quantifying the economic effects of animal disease, (2) developing methods for optimizing decisions when individual animals, herds or populations are affected, and (3) determining the profitability of specific disease control and health management programs and procedures.

The book has been designed as a guide to the field of animal health economics and its underlying methodology, and is primarily aimed at: (1) students in veterinary medicine, animal science, farm management and related fields, (2) veterinarians and extension personnel involved in providing animal health services, (3) government officials involved in disease control policy-making, and (4) research workers in animal health management. It is based on an international postgraduate course organized by the International Training Centre (PHLO), Wageningen Agricultural University in cooperation with the University's Department of Farm Management and the Massey University's Department of Veterinary Clinical Sciences, Palmerston North, New Zealand.

The book includes contributions from internationally recognized experts from the Netherlands, New Zealand, USA, UK and Kenya. These contributions range from a description of the basic economic framework and methods of economic analysis to more advanced techniques and risky decision-making procedures in animal health management. Their potential use and application in herd health control, government policy-making, and disease control in developing countries are also discussed. A diskette is supplied with the book, containing practical exercises (in computer spreadsheets) on the various methods and techniques in animal health economics, including production function analysis, partial budgeting, cost-benefit analysis, decision-tree analysis, Markov chain and Monte Carlo simulation, linear programming and dynamic programming.

We would like to thank the authors for their contributions, Diny Dijkhuizen for correcting the text, Gerdien van Schaik and Arnold Wierda for the lay-out of the manuscript and Ernst van Cleef for the design of the cover. We also owe thanks to the International Training Centre (PHLO), Wageningen Agricultural University, and the Dutch Ministry of Agriculture, Nature Management and Fisheries for their help and financial support.

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List of Tables

List of Figures

Animal Health Economics

principles and applications

1

How economically important is animal disease and why?

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Objectives

From this chapter the reader should gain knowledge of:

- the nature of the various effects of disease on feed intake and protein, energy and nutrient metabolisms
- the measurable effects of disease and disease control measures on livestock productivity

1.1 Introduction

The traditional distinction between animal health and animal production has become increasingly blurred in recent years, as the trends in livestock production systems have led advisers to progress from formerly looking at single technical issues to now consider multiple issues simultaneously in order to optimize the system. Greater and greater emphasis is being given to fine-tuning the management system by modifying various facets of the management strategy in response to monitoring data obtained from a farm. In the health area this trend has led to emphasis on subclinical diseases and their interaction with management, as the more spectacular and visible diseases have been brought under control. In dealing with animal health issues in livestock enterprises, economic evaluation has become increasingly important as the effects of the diseases which remain to be controlled are far more subtle than was the case for epidemic problems - where the question of economics did not have to be raised because the answer was self-evident. Before it is possible to develop appropriate techniques for improving the economic efficiency of a livestock enterprise through health management methods, it is first necessary to define the ways in which a particular disease lowers productive efficiency.

Over the years since animal health economics first developed, it has become clear from many studies that typically animal health measures yield very high economic returns to the livestock producer, although there are intriguing exceptions to this generalization. At first sight it is not clear why disease control should be any more profitable than other investments a farmer might make, or why this general finding is not universally true. In order to explain the unusual nature of the effects of disease on animals and hence to show how economic studies on animal disease should be carried out, it is first necessary to define the exact mechanisms by which a disease can influence productivity. This information is also relevant to animal scientists, who have in many cases failed to recognize the confounding influence of diseases in studies they undertake of management factors in livestock production.

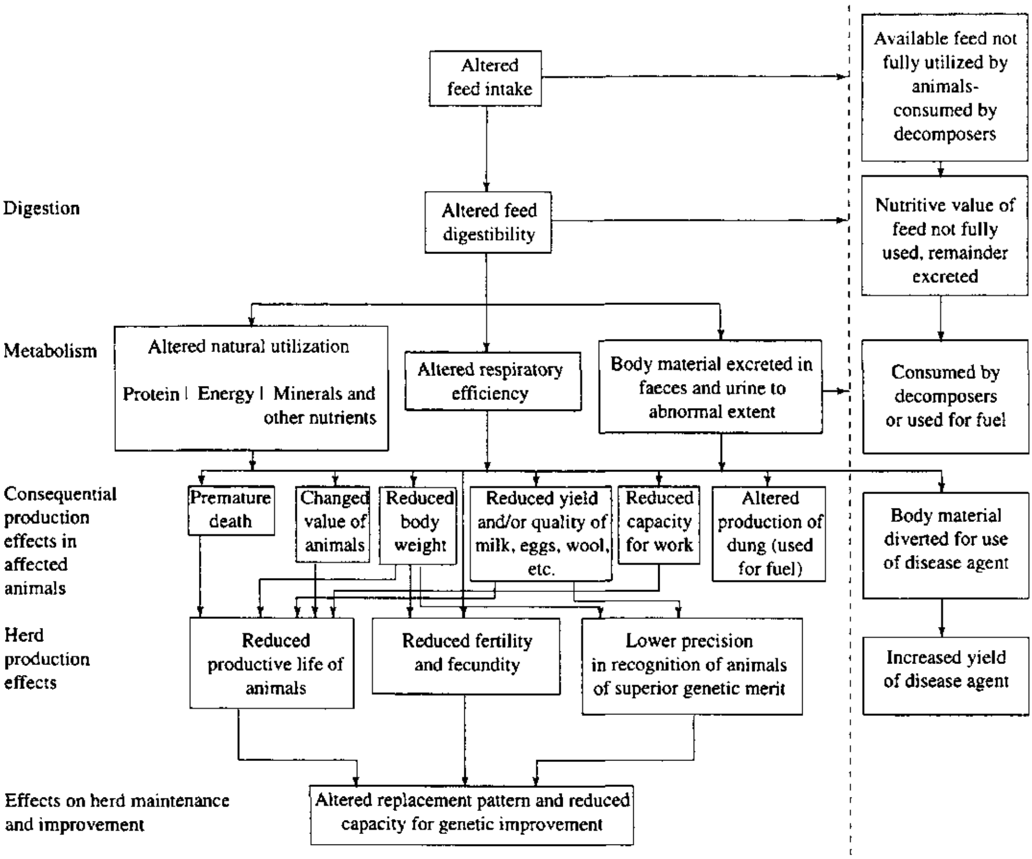

Figure 1.1 The various ways in which a disease may affect the productive value of animals in a herd or flock

1.2 Mechanisms by which disease may alter animal productivity

Figure 1.1 summarizes the various pathways through which disease can adversely affect the productivity of a livestock herd. In the case of **infectious** and **parasitic diseases** the under lying principle is that a disease agent is in constant competition with its host for access to nutrient supplies. The agent is successful if it can divert for its own use and reproduction, nutrients which the animal would otherwise have used for growth and production. The agent must therefore have some adverse effects on the host if it is to survive and multiply. **Non-infectious diseases** cannot be understood in the same way, but do frequently represent a change in ecological balance, in which the flow of nutrients and toxins (copper deficiency, facial eczema, etc.) or of controlling signals (hypocalcaemia, ketosis, etc.) through the agricultural ecosystem is distorted by human or environmental interventions of some type. The purpose of Figure 1.1 is to summarize all the possible direct and indirect mechanisms through which a disease can influence the productive efficiency of livestock. Not all diseases will have all of the effects, but an economic study should consider all possibilities and select for examination those which appear to be relevant. Each of the mechanisms is discussed individually, and then consideration is given to how they should be combined to evaluate the effect of disease on profitability.

Effects on ingestion

Many diseases alter **feed intake** in affected animals. In almost all cases intake is reduced, but rarely it may be increased. Diseases which cause pain during prehension (contagious ecthyma of sheep) or mechanical difficulty (actinobacillosis of the tongue in cattle) will reduce intake temporarily. Diseases which affect locomotor ability or reduce appetite due to a fever or similar discomfort will also lower intake. However, many diseases appear to reduce intake in subtle ways which may not be recognized unless careful measurements are made. These effects have been documented most carefully for parasitic diseases, although in some cases intake has been reduced only in more severe forms of the disease (Hawkins & Morris, 1978). Depression of feed intake can also occur in non-infectious diseases such as nutritional deficiencies (Scott *et al.*, 1980).

It is intriguing that feed intake should be commonly depressed by disease when other evidence shows clearly that **feed requirements** are increased by many of the same diseases, since productivity falls under the influence of the disease. From the limited studies which have been conducted to resolve this apparent paradox, it would appear that it results from disturbances in body homeostatic mechanisms of the host. Symons & Hennessy (1981) have found that cholecystikin levels rise as appetite falls in *Trichostrongylus colubriformis* infestations, and return to normal in line with appetite when the infestation is terminated. In the same disease, corticosteroid levels rise and thyroxine levels fall in response to the parasite, while insulin levels fall apparently in response to reduced intake rather than directly due to the parasite. It is important to differentiate between diseases which merely depress feed intake and those which lower the efficiency of feed conversion - with or without any effect on feed intake. The effect on intake is called the anorectic effect and that on feed conversion efficiency the specific effect. The specific effect is the more serious of the two, since lower production is achieved from the same feed intake, and efficiency of the production process is adversely affected, whereas the anorectic effect reduces both intake and output without altering the efficiency of production. This is an important consideration in studies of animals which consume purchased feed, such as pigs. It is less important in grazing ruminants, for which feed production is closer to being a fixed cost.

Effects of disease on feed digestibility

Disease agents do not normally seem to affect feed digestibility, even in the case of diseases which undoubtedly alter the morphology and physiological function of the gastrointestinal tract. In lambs, for instance, it was found that abnormal mucosa was not necessarily linked to poor growth, and it seems that changes in the mucosal surface itself are not responsible for the change in feed conversion efficiency which results from parasitism and other diseases, but rather the physiological processes that occur after absorption. Similar findings have been obtained with parasites such as *Fasciola hepatica* which do not cause mucosal changes (Hawkins & Morris, 1978). One of the few reports of a reduction in feed digestibility for ruminants was for magnesium deficiency in dairy cows (Wilson, 1980). However, the situation may be different in monogastric animals, since in pigs it was shown that internal parasites caused reductions in feed digestibility (Hale *et al.* 1981).

It nevertheless seems likely that at least in ruminants adverse effects of disease on productivity which cannot be explained by reduction in feed intake can reasonably be attributed to lower feed conversion efficiency; although digestibility trials are a crude method of assessing changes in digestive function. However, these trials are expensive and demanding, and studies of the economic effects of disease become easier to conduct if changes in digestibility can be disregarded as a major factor in altering feed conversion efficiency. It is also clear from the various studies in this general field that the nature and extent of pathological changes in the body cannot be used as any direct guide to the severity of effects of a disease on productivity.

Effects of disease on physiological processes

Diseases can modify many different physiological processes, such as nutrient metabolism, respiration and excretion. Most of the available data relate to parasitic diseases, but the evidence from these studies suggests that the fundamental effect is on protein metabolism. In gastrointestinal nematode infestations, plasma is lost into the digestive tract at the attachment sites of the parasites, and haemoglobin is also removed by blood-sucking parasites. Much of this protein is digested and reabsorbed lower in the tract, but the host uses energy and protein to replenish the mucosa and plasma proteins which have been depleted. This places demands on the liver and increases its nutrient utilization. There is increased excretion of nitrogen as urea in urine, demonstrating that recycling of the nutrients is not completely efficient in maintaining nitrogen balance, even though considerable energy costs are incurred by the host for increased protein synthesis.

Animals tend in these circumstances to run down their pool of plasma proteins because production in the liver cannot keep pace with the loss, even though the synthesis rate is unusually high. Adjustments are made to other nitrogen-using processes of lower priority, notably synthesis of wool protein and muscle protein. In sheep, sulphur-containing proteins are put in especially short supply by *Trichostrongylus colubriformis* infestation, demand cannot be met, and wool production shows an exceptionally large fall.

If feed intake is reduced either due to the parasite or to a low plane of nutrition, protein intake may fall below the level required to maintain an adequate serum protein pool. Bown *et al.* (1986) have shown that direct post-ruminal infusion of casein in sheep receiving daily doses of larvae of *Trichostrongylus colubriformis* increased nitrogen retention fivefold, and supported the argument as outlined above that the primary defect is one of protein loss and an anabolic cost of tissue regeneration. Infusion of glucose in amounts isocaloric with the casein only doubled nitrogen retention, showing that energy supplementation was not as beneficial as protein replacement.

A contrasting example to *Trichostrongylus colubriformis* is the cattle tick *Boophilus microplus*, which sucks blood much like some internal parasites, but differs in that the animal cannot recover any of the nutrient content of the blood in this case. In studies on the effects of ticks on host metabolism it was found that haemoglobin and plasma albumin fell, whereas globulin rose. Thus the animal was able to synthesize increased supplies of globulins, but could not maintain levels of the other blood constituents. This was attributed in part to a disturbance of protein metabolism, but the injection of a toxin by the tick was also hypothesized. To further emphasize the tenuous link between the pathology of a disease and its effects on productive processes, O'Kelly and Kennedy (1981) found that ticks adversely affected function in the gastrointestinal tract and reduced organic matter digestibility. It is difficult to explain why this should be so when such effects are not common for parasites directly affecting the tract.

Although these are the two most fully studied diseases, evidence for other diseases in a variety of species confirms the central importance of the derangement of protein metabolism in the disease process.

There is also impairment of energy metabolism, but this appears to be largely secondary to the alterations in protein metabolism, and is a result primarily of the energy costs of tissue regeneration. Mineral and micronutrient metabolic flows are also altered by parasitic diseases, which are the only ones to have been studied. There is reduced retention of ingested calcium and phosphorus in growing sheep infested with *Trichostrongylus colubriformis* or *Ostertagie circumcincta.* Consequently, bone growth and skeletal development are impaired; and this can reduce mature body size and capacity to accumulate muscle. Cobalt, copper and vitamin status of animals have all been reported to be affected by parasitism as well.

Since lung disease can adversely affect productivity, another mechanism by which disease might impair physiological function is a reduction in respiratory function. It seems more likely, however, that it is the regenerative process following lung disease which causes the production deficit.

1.3 Measurable effects of diseases on livestock productivity

The functional derangements described above translate into measurable economic effects in a number of ways, also summarized in Figure 1.1.

Premature death

This effect is the easiest of all the consequences of disease to measure, and therefore tends to be considerably overemphasized in comparison with other effects. In economic studies, death losses should be measured as the difference between the potential market value of the animal and its value when dead (which may not be zero), less the costs which would have been incurred in obtaining the market value (such as extra feed and care to market age, marketing costs, etc.).

Changed value of animals and products from slaughtered animals

Diseased animals may have lower market value either due to visible lesions or due to indirect changes in appearance or body confirmation which make them less attractive to buyers.

True market value of final products may be altered due to changes in the ratio of meat to fat or to bone or reduced protein content. The value of offals may also be reduced due to pathological changes caused by agents such as *Fasciola hepatica* or *Echinococcus granulosus*. Presence of lesions of a zoonotic disease may render the animal totally unfit for consumption.

Some diseases (such as caseous lymphadenitis in sheep) may render products less attractive to the consumer for aesthetic reasons, and hence may reduce meat consumption. Diseases which affect the skin, such as warble fly infestation or even sheep lice, may reduce the market value of hides or their value to the user.

Reduced live weight gain

There have been very many studies published on the effect of diseases on weight gain in animals, and in general they find that diseased animals gain weight more slowly than equivalent disease-free animals. Notable as an exception is lice infestation in cattle. Differences in weight gain between infested and lice-free animals are modest or negligible, and certainly not enough to yield an economic benefit from treatment. Therefore caution is required in assuming an effect on weight gain of a disease without experimental data to support it.

Reduced yield and quality of products from live animals

Yield of products such as milk, wool and eggs may also be reduced by disease, and there have been numerous papers showing the effect of various diseases on wool growth or milk yield. Quality of the products may also be reduced, as in the case of the changes in milk composition which result from bovine mastitis, and which may or may not be detectable by the consumer. In the first case price will fall and the livestock producer will suffer; in the second case, the consumer will suffer the loss. It has also been shown that disease can affect the taste of meat (Garriz *et al.*, 1987).

Reduced capacity for work

Worldwide, the single most important use of animals is as a source of traction. The second largest (after dung) productive energy output of animals in developing countries is for work; products considered of central importance in developed countries are seen as byproducts in developing countries. There have been no published reports directly measuring the effects of diseases on capacity for work, but field evidence is that diseases can severely curtail rice paddy preparation and other tasks for which animals are essential, so this effect can be very important and should therefore be considered in developing countries.

Altered production of dung for fuel and fertilizer

In Asia and Africa cattle dung is a vital source of cooking fuel, and in much of the developing world it is an important fertilizer. Diseases which cause high death rates in cattle will also indirectly influence human nutrition by reducing dung supplies.

Altered feed conversion efficiency

As discussed earlier, it appears that disease primarily affects animal productivity by altering the metabolic processes for protein and other nutrients, thereby reducing the feed conversion efficiency of affected animals and producing a number of ramifications which reduce herd productivity. Feed intake may also be reduced, but this is not usually the primary effect.

Feed conversion efficiency is the ultimate measure of the influence of disease on the production process, but its measurement requires accurate measurement of feed intake, which is only possible under controlled feeding conditions. In grazing systems it is usually reasonable to take changes in productivity as an adequate indication of changes in feed conversion efficiency when comparing diseased and disease-free animals kept under identical conditions.

Intuitively, it seems likely that the rate of decline in productivity would increase as the disease becomes more severe, and body functions become more deranged. However, the limited evidence available favours the alternative view that the most dramatic changes occur at low or subclinical levels of disease, and that each additional parasite, for example, has less effect than the one before it (Hawkins & Morris, 1978). This emphasizes the importance of the health management approach in which the focus is on optimizing productive efficiency rather than the clinical approach in which a disease must be detectable to be considered important.

1.4 Effects of disease on herd productivity

The effects of disease flow through from consequences for individual animals to broader ramifications for herd replacement and improvement.

Reduced productive life of animals

Apart from animals which die, all remaining herd members are culled when the farmer considers them less potentially productive than the animal which would replace them. This issue has been investigated in detail in the Netherlands (Van Arendonk, 1985; Huirne, 1990; Houben, 1995) and in Denmark (Kristensen, 1993). They showed that in general a substantial economic benefit could be achieved by taking action to extend the **herd life** of the average dairy cow or sow, principally by reducing the amount of culling due to ill health. This is not limited to disposal specifically because of disease, but also includes culling for low yield or other reasons, where the underlying cause is lowered productivity due to disease, and the farmer being unaware of this fact.

Less accurate genetic selection

If a disease alters any of the components of productivity which are the subject of genetic selection pressure in the herd (such as milk or wool yield), it will affect the efficiency with which animals of superior genetic merit are identified, especially if the probability of an animal being affected by the disease is unrelated to yield level. Provided susceptibility to the disease and yield level are not correlated, the presence of the disease will confound the genetic selection effort. For example, it was shown that internal parasitism can affect wool production by sheep in ways which distort selection by objective measurement of wool characteristics. Since, for practical purposes, resistance to internal parasitism cannot be regarded as a heritable trait, genetic selection will be more efficient if effective parasite control is carried out in the herd.

Effects on capacity to maintain and improve the herd

If less progeny are born, fewer animals are available as herd replacements or for sale as market products. Thus not only will livestock sale income be reduced, but also management flexibility for herd improvement will be curtailed. It is self-evident that diseases of the reproductive tract in both males and females can substantially reduce the level of reproductive performance, and hence the number of progeny born in the herd. Less obviously, diseases which adversely affect body metabolism (but do not directly affect the reproductive tract) can also affect the number of progeny born. The mechanisms have not been fully explored, but may well operate through an effect on live weight and condition, or through indirect means such as the induction of pyrexia at critical stages in the reproductive process. For example, both gastrointestinal parasites and liver fluke have been shown to affect reproductive performance in ewes. In cattle, bovine leucosis and ephemeral fever have been reported to affect reproduction.

If reproductive performance is too poor, it may even become impossible to maintain herd size through home-bred replacements, necessitating the purchase of breeding animals with all the additional risks which that entails.

1.5 Effect of disease control measures on productivity of animals

In evaluating the economic benefit of disease control, it is necessary to consider not only the difference in productivity between diseased and disease-free animals, but also the changes in productivity which follow elimination of a disease from an affected animal.

This has not been studied for very many diseases, but some examples exist. For instance, bovine mastitis appears to be a disease for which complete regeneration occurs in most animals over the dry period following elimination of an infection (Morris, 1973), although yield remains depressed for the rest of the lactation in which a cure is achieved. Conversely, when infestations with *Fasciola hepatica* are eliminated in growing animals, sheep do not regain their former productivity or feed conversion efficiency. Therefore each disease type must at least in the first instance be considered separately, since the nature and extent of recovery following elimination of a disease is not predictable from general principles. The selection of an economically optimal control strategy will be strongly influenced by this consideration.

1.6 Effects of animal disease on human and animal welfare

Effects on human nutrition

The major direct effect of animal disease on human well-being is through reducing the supply of high quality protein, for example, diseases which reduce the supply of milk for young children. Animal products are also important sources of other nutrients, notably minerals and vitamins, and diseases can both reduce the total supply of animal products and modify the composition of animal products in ways which reduce their nutritional value.

Effects on community development

As well as the effects on human nutrition, animal diseases can affect other aspects of community welfare, especially in developing countries. As discussed earlier, the two most important services provided by animals in such circumstances are traction and dung production. Disease may reduce the supply of both of these. Animals are also important sources of products (wool, hair, hides, feathers, fur, etc.) used for clothing, decoration and for the manufacture of utensils and other products. A further effect of those animal diseases which are zoonotic is to cause disease in the human as well as the animal population, thus amplifying their impact.

Cultural significance of animals

In most communities animals serve functions far beyond the utilitarian roles which are the focus of this chapter. While these are not strictly economic in nature, they are vital functions which should be included in any consideration of the significance of animal disease.

Animal welfare

In considerations of animal welfare issues, little is said about the importance of ensuring through disease control that animals are in a healthy state - yet this is a vitally important issue in protecting the welfare of managed animals. It deserves more prominent attention in discussions of animal welfare matters. There have been surprisingly few efforts to quantify welfare effects of diseases, and most of the information available is opinion rather than solid evidence. However, some efforts have been made to define just what the effects are (Gibson, 1987; Webster, 1995). Some of the mechanisms through which disease affects the welfare of animals are starting to be elucidated (Rothwell & Dantzer, 1992). However, greater biological understanding will be needed before quantitative assessments of the effect of disease on animal welfare can be attempted.

1.7 Methods of measuring the economic benefit of animal disease control

The past practice of considering the cost of disease was unsound, and has given way to economically sound analyses which estimate the economic benefit of control measures (Schepers & Dijkhuizen, 1991). Many such studies have been published over recent years, and there are good published models for analyses of most major types of diseases.

Such studies will have the greatest realism and practical relevance if they are conducted on farms. The simplest approach is to compare alternative control programs within farms, provided that this is epidemiologically sound for the particular disease. Ideally, a number of farms should be included in such studies to obtain estimates of variation in outcome between farms. In some cases it may be necessary to conduct a comparison solely between farms because the farm is the smallest feasible experimental unit. This is quite practical but requires a large number of farms because of the extent of variation in uncontrolled factors between farms.

There are standard **economic techniques** which should be used to describe and summarize the outcome of economic studies. The most common ones are partial budgeting, cost-benefit analysis and decision analysis. Each of these techniques, their application and limitations are discussed in more detail in following chapters of this book.

The focus of economic studies must be on estimating the benefit of action against a disease, rather than just on the economic impact of the presence of a disease. Although it is not possible to get all of the economic data which might be desired for every disease, experimental studies can now be supplemented and expanded using other analytical approaches, of which computer modelling is among the most useful. It is also necessary, in cases where chance is an important element in the epidemiology of the disease, to include an evaluation of the riskiness of each of the alternative courses of action in economic studies. There are standard economic procedures for doing this, which are also discussed in following chapters.

1.8 Concluding remarks

If the understanding of disease processes and their effects described above are to form the basis for veterinary services to livestock, then the focus of these services needs to be one of **health management** rather than principally **disease treatment**. A rational approach to provision of health care requires that the productive and welfare significance rather than the pathological severity of the disease should be the measuring stick for livestock. In this way health and production issues can be brought together for the benefit of the livestock producer and equally of the consumer.

References

Bown, M.D., Poppi, D.P. & Sykes, A.R., 1986. The effect of post-ruminal infusion of protein or energy on the pathology of *Trichostrongylus colubriformis* infection on body composition in lambs. Proceedings of the New Zealand Society of Animal Production 46: 27-30.

Garriz, C.A., Gallinger, M.M., Touraille, C., Steffan, P.E., Fiel, C.A., Ambrustulo, R.R., Biondani, C.A., Zamorano, M. & Bulman, G.M., 1987. Gastrointestinal parasitism: its effects on muscle, fat and bone composition of the carcass and organoleptic characteristics of meat. Proceedings MSDAgvet Symposium on Gastrointestinal Parasitism, August 19, 1987: 59-68.

Gibson, T.E. (ed.), 1987. Animal disease - a welfare problem? British Veterinary Association Animal Welfare Foundation, 96 pp.

Hale, O.M., Stewart, T.B., Marti, O.G., Wheat, B.E. & McCormick, W.C., 1981. Influence of an experimental infection of nodular worms *(Oesophagostomum* spp.) on performance of pigs. Journal of Animal Science 52: 316-322.

Hawkins, C.D. & Morris, R.S., 1978. Depression of productivity in sheep infected with *Fasciola hepatica*. Veterinary Parasitology 4: 341-357.

Houben, E.H.P., 1995. Economic optimization of decisions with respect to dairy cow health management. PhD-Thesis, Department of Farm Management, Wageningen Agricultural University, Wageningen, 146 pp.

Huirne, R.B.M., 1990. Computerized management support for swine breeding farms. PhD-Thesis, Department of Farm Management, Wageningen Agricultural University, Wageningen, 165 pp.

Kristensen, A.R., 1993. Markov decision programming techniques applied to the animal replacement problem. Doctoral dissertation, The Royal Veterinary and Agricultural University, Copenhagen, 183 pp.

Morris, R.S., 1973. The depression of quarter milk yield caused by bovine mastitis, and the response of yield to successful therapy. Australian Veterinary Journal 49: 153-156.

O'Kelly, J.C. & Kennedy, P.M., 1981. Metabolic changes in cattle due to the specific effect of the tick *Boophilus microplus*. British Journal of Nutrition 45: 557-566.

Rothwell, N. & Dantzer, R., 1992. Interleukins in the brain. Oxford: Pergamon Press, 207 pp.

Schepers, J.A. & Dijkhuizen, A.A., 1991. The economics of mastitis and mastitis control in dairy cattle: a critical analysis of estimates published since 1970. Preventive Veterinary Medicine 10: 213-224.

Scott, P.R., Kelly, J.M., Whitaker, D.A. & Cameron, N.D., 1980. Marginal magnesium deficiency as a possible cause of reduced voluntary intake in commercially managed dairy cows. Veterinary Research Communications 4: 225-229.

Symons, L.E.A. & Hennessy, D.R., 1981. Cholecystikin and anorexia in sheep infected by the intestinal nematode *Trichostrongylus colubriformis*. International Journal of Parasitology 11: 55-59

Van Arendonk, J.A.M., 1985. Studies on the replacement policies in dairy cattle. PhD-Thesis, Department of Animal Breeding and Department of Farm Management, Wageningen Agricultural University, Wageningen, 126 pp.

Webster, A.J.F., 1995. Understanding the dairy cow. BSP Professional Books, Oxford, 357 pp.

Wilson, G.F., 1980. Effects of magnesium supplements on the digestion of forages and milk production of cows with hypomagnesaemia. Animal Production 31: 153-157.

2

Economic decision making in animal health management

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Objectives

From this chapter the reader should gain knowledge of:

- basic principles underlying economically sound decision making
- major components of a conceptual model for economic analysis
- production function principles
- cost functions

2.1 Introduction

Economics is sometimes qualified as the discipline that simply measures things in monetary units, while everyone else uses physical units. This view, however, is far too simple and inappropriate. Economics - as a science - primarily deals with **decision making**, whereby money is only one of the elements. **Animal health economics**, therefore, can be described as the discipline that aims to provide a framework of concepts, procedures and data to support the decision-making process in optimizing animal health management (Dijkhuizen, 1992).

Controlling the cost of production is becoming critically important in modern livestock farming. Improving animal health and fertility can play a major role in achieving efficient and economically rewarding production. Current veterinary services are evolving to meet the need for service targeted tightly to the needs of farmers through planned disease prevention and control programs and management for optimum health. The application of these services is rarely an all-or-nothing affair. Usually several programs or measures are available, each of them offering a different degree of protection and requiring a different level of investment. Determining the optimum input level, therefore, is to a large extent a matter of economic decision making. Not only is this the case for the individual livestock owner, but also for a national government that must determine an optimum policy on specific contagious diseases. In this chapter the basic economic framework and principles to rely on when dealing with these aspects are discussed and illustrated.

2.2 The basic economic model

The basic conceptual model underlying economic analyses includes three major components: people, products and resources. It is **people** who want things and make decisions, therefore being the driving force for economic activity. **Products** are goods and services that satisfy people's needs and may be regarded as the outcome of economic activity. **Resources** are the physical factors and services that are the bases for generating the products, and, as such, are the starting points of economic activity. These three components can be put together to portray the basic conceptual model that underlies economic analysis (Figure 2.1).

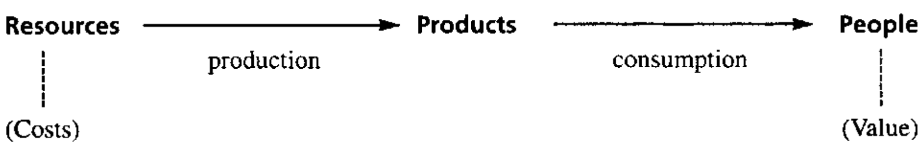

Figure 2.1 The basic model underlying economic analysis (Howe & McInerney, 1987)

In Figure 2.2 animal disease is portrayed in the system as an influence which affects the livestock resource transformation process and results in extra resource use and/or fewer animal products than before (**direct effects**). These direct losses may be immediately visible (death, abortion), or obscured (reduced milk yield). Animal disease may also affect other parts of the economic system, thus diminishing benefits to people (**indirect effects**). These indirect losses can be divided into those that are fairly obvious (collapse of export trade), and those that are obscure (constraints on agricultural developments).
Probably the most useful addition to this basic economic model for certain decision situations would be to include a loop indicating that some animal 'products' are not used for human consumption but as breeding stock, and so form part again of the resource base. In doing this the notion of 'capital' is introduced.

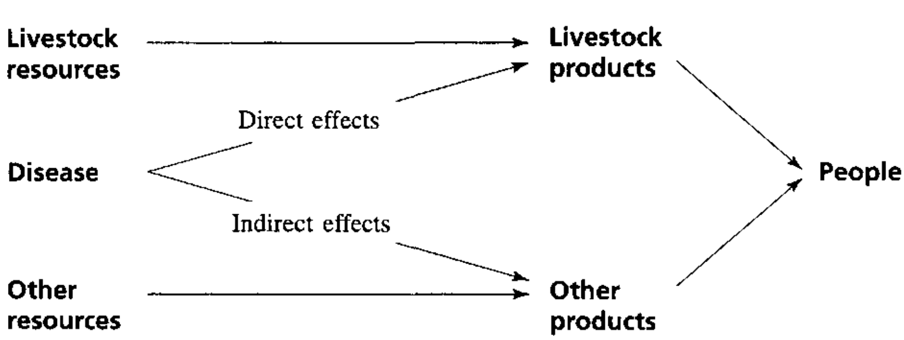

Figure 2.2 Livestock production in the wider economic system

To express the physical effects in economic terms, the 'value' of products and 'cost' of resources are required. The idea of value is not intrinsic in any product or service, but is determined by the people's request for the products, and is relative to their availability ('supply and demand'). Economics attempts to deal with the real value of any product, which may or may not be accurately captured in its recorded price. Similarly, the idea of cost stems from the resources that are used in making a product available. This underlies the definition of the real cost (or **'opportunity cost'**). The opportunity cost of using a resource in a particular way is the value of that resource if it were used in the best alternative way, which again may not adequately be reflected by financial expenditures incurred in its production. Both 'real value' and 'real cost' - and hence the losses from one and the same disease - may differ considerably across the various economic levels to be considered, ie, the individual farmer, the joint livestock owners, the consumers and the national economy, as is illustrated in Table 2.1.

In the case of the **common diseases** that the individual farmer can control (eg, mastitis), supply and demand force animal product market prices to change over time with the average disease level. Thus the resulting losses are transferred to the consumers, and conversely it is the consumer who benefits from improved animal health. On a sufficiently large market (such as the European Union) there is hardly any relation between the extent and severity of these diseases on the one hand, and the average income of the joint livestock owners on the other. However, for the individual farmer this linkage does exist. The farm in question may suffer more (or less) from disease than is compensated for by the average 'disease margin' included in the market price. To a lesser extent this also applies to a group of livestock owners.

In the case of an epidemic of **contagious diseases** (eg, foot-and-mouth disease), market prices of output primarily depend on whether or not restrictions on foreign trade will be im posed. When an outbreak does not lead to export bans, the market prices may temporarily rise a little, depending on the spread and duration of the outbreak. If exports are restricted, however, prices in countries that export much will drop substantially due to an oversupply on the domestic market. This fall in price causes losses which may greatly exceed the direct losses from the disease owing to, for instance, mortality. Unaffected farms also suffer from this drop in market prices. Consumers will benefit, however, making the losses to the national economy considerably fewer than those to the joint livestock owners.

2.3 Veterinary services as an economic input factor

2.3.1 Production function principles

The calculation of the economic losses is not only important for a description of the actual situation, but also for how, and more specifically, to what extent it can help to answer questions such as: (1) how to limit the losses as much as possible if diseases do occur, and (2) in what way and to what extent can the risk of disease be diminished, how much loss can be avoided and what efforts and costs are involved? To base the answers on sound economic criteria, insight into the relationship between the input and output of disease control (ie, veterinary services) is essential. Here, production function and cost analysis play a central role.

The technical relationship between the amount of input(s) and the output produced is

Table 2.1 Losses due to animal disease at various economic levels

Economic level	Type of disease: A. Disease generally present, but varying in degree per farm	B. Outbreaks of contagious diseases on a national or regional scale: B1. Foreign trade restrictions	B2. No foreign trade restrictions
1. Farm (individual producer)	Direct relation between loss and degree of the disease per farm. Particularly in pig and poultry farming great effect on income.	Great incidental loss, even if the farm is not affected by the disease. Possible compensation for destroyed animals.	Great loss to the affected farms (possible compensation for destroyed animals); advantage to farms not affected.
2. Sector (joint livestock farmers)	Loss, if the price does not adjust itself. On a sufficiently large market (eg. the EU) hardly any relation between level of disease and income of livestock farmers, due to price adjustment.	Significant loss, particularly in the case of export products, resulting from dropping prices owing to failing demand.	Moderate loss (depending on possible compensations and on degree of price adjustments).
3. Supply and processing industries; service and trade[a]			
4. Consumer	Loss owing to higher prices.	Incidental advantage.	Slight loss.
5. National economy	Loss owing to inefficient use of resources.	Disadvantage considerably less than loss to joint farmers (2B1).	Disadvantage can be more than to joint farmers (2B2), but less than 5B1.

[a] Possible effects have not been specified. Price changes are assumed to be passed on to the consumer fast and completely.

referred to as the factor-product relationship or the production function (Boehlje & Eidman, 1984). It is also commonly referred to as the input-output relationship or response curve. The relationship relates to the amount of products that can be produced for alternative combinations of inputs within a specified time interval, for example one year. If X_i represents the amount of the i^{th} input (eg, veterinary services) and Y represents the amount of products produced (eg, kg of weight gain), then the production function can be written as:

$$Y = f(X_1 | X_2, \ldots, X_n)$$

This relationship indicates that the amount of product Y is a function of the amount of variable input X_1 and the level of the fixed inputs X_2 through X_n.
The relationship between the amount of a single variable input and the output of a single product can take one of three general forms: constant productivity, diminishing productivity and increasing productivity of the variable input. **Constant productivity** exists when each additional unit of variable input added to the fixed factor(s) increases output by the same amount. With **diminishing productivity** each additional unit adds less to total output than the previous one, whereas with **increasing productivity** the opposite occurs. The most classical production function is assumed to include both **increasing and diminishing productivity**, as is illustrated in Figure 2.3.
Total physical product (TPP_{X1}) grows at an increasing rate until output level *a* is reached, and increases at a decreasing rate between *a* and *c*. Beyond output level *c*, total physical product declines with increased input of X_1.
Two other technical relationships - the marginal physical product (MPP_{X1}) and the average physical product (APP_{X1}) - can be derived from the production function and are important in selecting the optimum amount of a variable input. **Marginal physical product** is the increment to total physical product attributable to the addition of a single unit of input ($MPP_{X1} = \Delta TPP_{X1}/\Delta X_1 = \Delta Y/\Delta X_1$) and is, therefore, equal to the slope of the TPP curve at any level of input. **Average physical product** is equal to the average output per unit of variable input and is calculated as total physical product divided by the amount of variable input used ($APP_{X1} = TTP_{X1}/X_1 = Y/X_1$).
From these relationships, three stages of production can be defined, as is also shown in Figure 2.3. Stage 1 is defined as the area in which marginal physical product is larger than average physical product. In Stage 1 the MPP_{X1} curve increases, reaches its maximum (when output gets to level a), and then declines. Average physical product increases throughout the stage and reaches a maximum at the boundary between Stages 1 and 2 (when output gets to level b). Notice that at this boundary marginal physical product and average physical product are equal. Within Stage 2 marginal physical product is further declining, and reaches zero at the boundary between Stages 2 and 3 (when output gets to level c).
Average physical product is declining and positive throughout Stage 2. Stage 3 is characterized by declining total physical product and negative (and declining) marginal physical product. Average physical product, of course, continues to decline in Stage 3.
The three stages provide the decision maker with useful information in defining the range

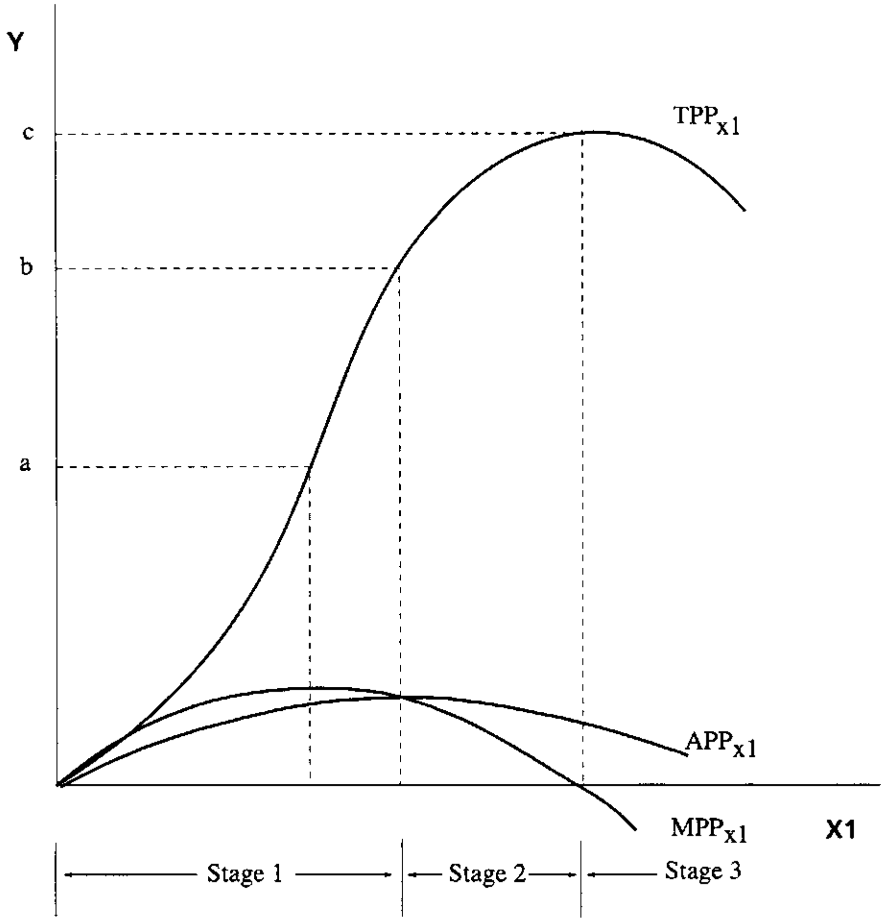

Figure 2.3 The classical production function

which is the most efficient for production. It would be irrational to operate in either Stage 1 or Stage 3 regardless of the level of input and product prices. It is obvious that one would not want to operate within Stage 3. Applying additional units of the variable input and forcing production into Stage 3 reduce the amount of total product produced. If the prices of the variable input and the product are assumed to be constant and positive, one would make more money by leaving some of the variable input unused. Producing within Stage 1 is not rational either, because a more efficient use of the variable input can be obtained by higher levels of input until the APP_{x1} curve reaches its maximum. Production, therefore, should always occur in Stage 2, but the decision maker must consider the prices of input and output in order to determine exactly the profit-maximizing level of the variable input to be used.

To better illustrate the three technical relationships discussed before, a hypothetical response to anthelmintic dosing in growing cattle is summarized in Table 2.2

In Table 2.2 the average physical product curve reaches its maximum with five doses, indicating the boundary between Stages 1 and 2. This boundary is further confirmed by the fact that the marginal product curve intersects with the average product curve. The marginal physical product curve falls below zero beyond six doses, being the boundary between Stages 2 and 3. The rational range, therefore, is narrow in this case and includes five and six doses only (Stage 2).

Table 2.2 Hypothetical response to anthelmintic dosing in growing cattle

Number of doses	Total physical product (kg of weight gain)	Average physical product (kg per dose)	Marginal physical product (Δ kg / Δ dose)
0	0	0	
1	10	10	10
2	30	15	20
3	60	20	30
4	100	25	40
5	130	26	30
6	150	25	20
7	140	20	-10
8	120	15	-20

2.3.2 Cost functions and economic choice

Cost functions are closely related to production functions. They take into account an additional step and include the cost of the various inputs in the input-output relationship. The total cost curves related to the classical production function of Figure 2.3 are shown in Figure 2.4.

As shown in Figure 2.4, cost curves are depicted with the cost on the vertical axis and the amount of output on the horizontal one (notice that the latter was on the vertical axis with the production function in Figure 2.3). The relationships for **total variable cost** (TVC), **total fixed cost** (TFC) and **total cost** (TC) are given by the following equations (with P_{xi} being the input prices):

$$TVC = P_{x1}X_1$$

$$TFC = \sum_{i=2}^{n} P_{xi}X_i$$

$$TC = TVC + TFC = \sum_{i=1}^{n} P_{xi}X_i$$

Notice the corresponding relationship between the production function (Figure 2.3) and the total variable cost curve (Figure 2.4). Output in Figure 2.3 grows at an increasing rate until output level *a* is reached. The total variable cost curve in Figure 2.4 increases at a decreasing rate within the same range of output. Within Stage 2 (output level *b* to output

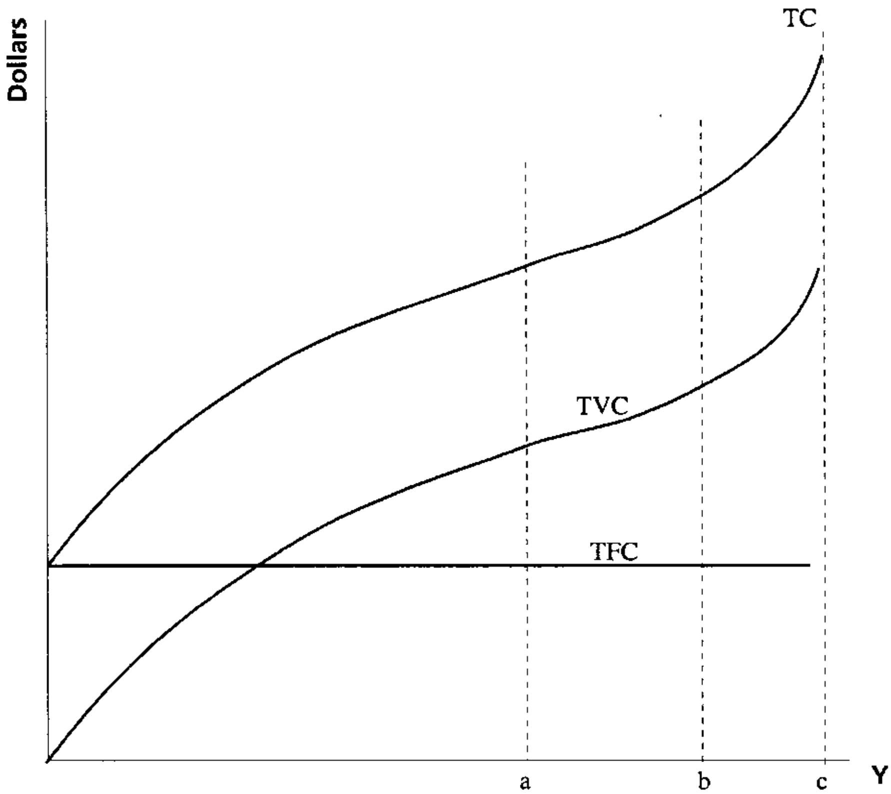

Figure 2.4 Total cost functions (identifying 3 stages of production)

level *c*), total output is increasing at a decreasing rate and total variable costs are rising at an increasing rate. The total cost curves become vertical at output *c*, the boundary between Stages 2 and 3. The vertical curve reflects the fact that cost continues to increase while the addition to output is zero. Total variable costs and total costs would continue to increase as the output level declined, resulting in total cost and total variable cost curves to bend back to the left as they increase. The shape reflects the irrationality of producing in Stage 3. Higher cost levels would be incurred for production of an amount of output equal to that in Stage 2.

The average and marginal cost curves for the classical production function are shown in Figure 2.5. The relationships for the **average fixed cost** (AFC), **average variable cost** (AVC), **average total cost** (ATC) and **marginal cost** (MC) are given by the following equations (with P_{Xi} being the input prices):

$$AFC = TFC / Y$$
$$AVC = TVC / Y = P_{X1}X_1 / Y = P_{X1} / APP_{X1}$$
$$ATC = AFC + AVC$$
$$MC = \Delta TC / \Delta Y = P_{X1}\Delta X_1 / \Delta Y = P_{X1} / MPP_{X1}$$

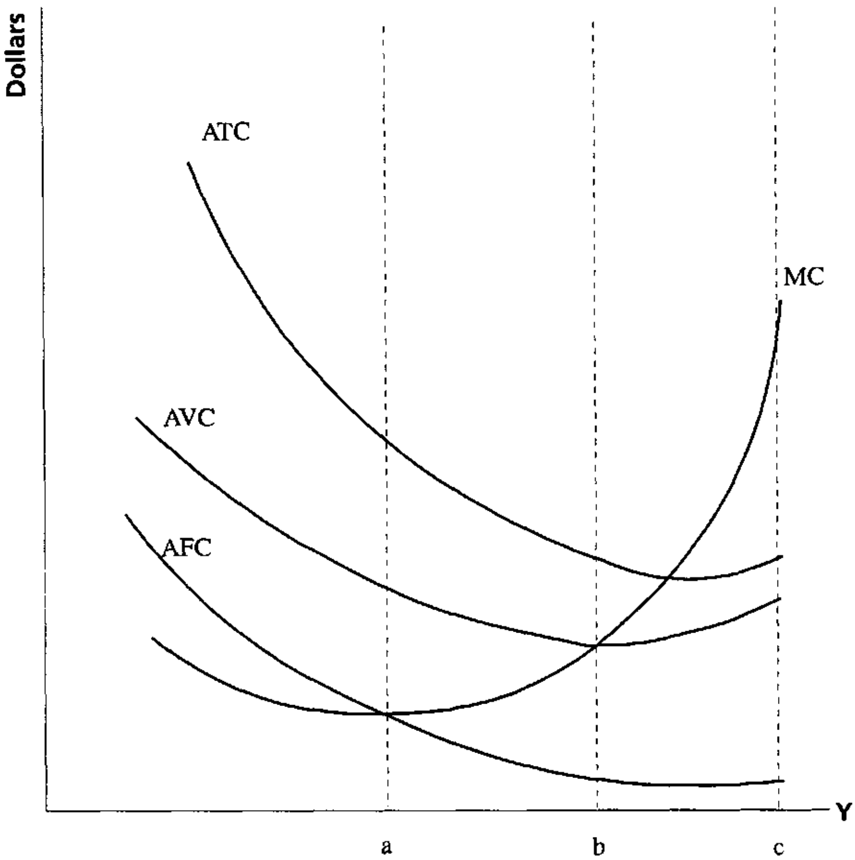

Figure 2.5 Average and marginal cost functions

The minimum average variable cost occurs, as could be expected, at the output level having the maximum average physical product, the boundary between Stages 1 and 2 (indicated by output level *b*). Marginal cost is at a minimum where the MPP_{X1} is maximum - output level *a* in Stage 1 of production. Marginal cost increases when MPP_{X1} declines. It is equal to average variable cost at the boundary between Stages 1 and 2, where $APP_{X1} = MPP_{X1}$. Within Stage 2 net returns will be increased (or losses reduced) by using higher levels of the variable input as long as the marginal cost is lower than the output price ($MC<P_y$). The simple logic is that each additional unit of output produced adds more to gross returns than to cost when $MC<P_y$. **Profit, therefore, is maximized where marginal cost and returns are equal** (in Stage 2).

It is of interest to notice that various cost-minimizing rules are unlikely to lead to profitable output levels. For example, a rule to minimize average variable cost would result in selecting the input level *b* at the boundary between Stages 1 and 2. If P_y is greater than MC at this level, profit can be increased by operating at a higher output level. In the event P_y is less than the minimum AVC, losses will be minimized (ie, reduced to TFC) by ceasing production.

That will make the **supply curve** for a farm identical to the marginal cost curve for all values of prices that exceed average variable cost.

The cost calculations are illustrated in Table 2.3 using the data from Table 2.2 on the hypothetical response to anthelmintic dosing in growing cattle. Fixed costs per head are assumed to be US$100, and input price US$10 per dose.

Table 2.3 Production cost derived from the production function on the hypothetical response to anthelmintic dosing in growing cattle

X1 doses	Y kg	TFC $/head	TVC $/head	TC $/head	AFC $/kg	AVC $/kg	ATC $/kg	MC $/kg
0	0	100	0	100	—	—	—	
1	10	100	10	110	10.00	1.00	11.00	1.00
2	30	100	20	120	3.33	0.67	4.00	0.50
3	60	100	30	130	1.67	0.50	2.17	0.33
4	100	100	40	140	1.00	0.40	1.40	0.25
5	130	100	50	150	0.77	0.38	1.15	0.33
6	150	100	60	160	0.67	0.40	1.07	0.50
7	140	100	70	170	0.71	0.50	1.21	—
8	120	100	80	180	0.83	0.67	1.50	—

The values in Table 2.3 are calculated using the equations presented before. Average variable costs (AVC) are minimal with five doses (US$0.38/kg). The output price P_y (ie, the so-called marginal return), therefore, should not be less than US$0.38/kg, otherwise losses will be minimized (ie, reduced to TFC) by ceasing production. A higher price will make six doses the optimum. More than six doses are not an option because of the negative marginal results. These findings are in agreement with Table 2.2, where five and six doses were found to form the rational range (ie, Stage 2).

Exercise

You can practise the principles of a production function, as discussed in this chapter, with the spreadsheet example in Chapter 19: the farm advisory case. The effects of veterinary services on the number of piglets weaned on a sow farm are shown in a production function. You have to calculate the different cost functions and to find the economically optimal amount of veterinary input. Sensitivity analyses are done to show the effect of changing prices. This exercise takes about 45 minutes. A smaller example with real experimental data on anthelminthics in ewes can give you an indication of how this theory is used in research: you have to find the optimal treatment for this disease. This extra exercise takes about 30 minutes.

2.3.3 Further applications

In considering the production and cost function approach, it was assumed that only one control measure (ie, input) was varied, and all other aspects were held constant. However, in reality various different control measures are usually available and it is not just a matter

of deciding with what intensity each individual control measure will be applied, when the intensity of the other ones is held constant. It is necessary to face the question of deciding the optimum combination of two or more measures as well.
The optimum combination of two inputs can again be found by using the marginal principle - the optimum point is where the reduction in cost by eliminating one unit of input A (eg, teat dipping in mastitis control) equals the cost of the additional amount of input B (eg, dry-period therapy in mastitis control) to keep the output (eg, milk production) constant. Just as an optimum combination of two inputs can be found, it is possible to calculate the best combination of a larger number of inputs in a similar way. The concept is simple, and formally named the **equimarginal principle**:

> The returns from a scarce or limited resource are maximized when the input is allocated to its most profitable uses in such a way that the returns from the last unit of resource is not only equal or higher than the costs of the last unit of resource, but also the same in each of the alternative uses.

In this way funds will be spread among uses according to their marginal returns (which will of course decline progressively as more funds are invested in a single item). This principle is easy to understand and to use; and is a very powerful economic tool. Yet all too often decisions in animal health management (and elsewhere) are not made in accordance with this principle, either because the information does not exist or because farmers and advisers do not know of it. It is a challenge for both veterinarians and animal health economists to make proper estimates of marginal cost and returns from disease control measures. Once these estimates are available, calculations can easily be redone with other input values to help determine the impact of uncertain estimates on the outcome of the decisions (a so-called **sensitivity analysis**).
There is a wide range of techniques available to help perform these analyses for two or more measures and for more realistic and complicated situations. Both basic methods (ie, partial budgeting, cost-benefit analysis, decision-tree analysis) and advanced techniques (ie, linear programming, dynamic programming, Markov chain simulation, Monte Carlo simulation) are discussed and illustrated in the following chapters.

References

Boehlje, M.D. & Eidman, V.R., 1984. Farm management. John Wiley & Sons, New York, 806 pp.

Dijkhuizen, A.A., 1992. Modelling animal health economics. Inaugural speech, Wageningen Agricultural University, Wageningen, 28 pp.

Howe, K.S. & McInerney, J.P. (eds), 1987. Disease in livestock: economics and policy. EUR 11285 EN, Commission of the European Communities, Brussels, 190 pp.

3

Basic methods of economic analysis

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Objectives

From this chapter the reader should gain knowledge of:

- the need for farm accounting systems
- the concept of farm enterprise budgets
- the basic economic methods: partial budgeting, cost-benefit analysis and decision analysis

3.1 Introduction

In Chapter 2 it was stated that the application of veterinary services is rarely an all-or-nothing affair. Usually several programs or measures are available, each of them offering a different degree of protection and requiring a different level of investment. The basic economic principle for determining the optimal level of input is called the **equimarginal principle**: the input should be allocated to its most profitable uses, such that the returns from the last unit (marginal returns) is not only equal or higher than the costs of the last unit of resource (marginal costs), but also the same in each of the alternative uses.

The principle is simple, but its application becomes more complicated when the number of inputs to decide on and the range of options to choose from increase. Methods are available, however, to help to carry out these more complicated analyses. In this chapter some basic methods are presented, including partial budgeting, cost-benefit analysis and decision analysis. More advanced methods follow in Chapters 5 to 9. All these methods make use of information, and that is why the need for farm accounting systems is discussed first. Furthermore, the concept of enterprise budgets and gross margin analysis is introduced. This is because the basic economic methods are usually applied to only a part of the farm, ie, to a single enterprise.

3.2 The need for farm accounting systems

Accurate and efficient decisions on animal health management require extensive information. Some of this information can be acquired from farm records, while other data must be obtained from firms with which the farmer deals, or other public and private agencies (Boehlje & Eidman, 1984). Record keeping and accounting can be tedious, complex and time-consuming. However, it can also be very rewarding when it provides the essential data for performance evaluation and assessment of progress that are important in managing animal health.

While there are many reasons for keeping farm accounts, the use of accounts in animal health management can be summarized under two headings: (1) to provide data for forward planning, and (2) to help control the operation.
Farm accounts can provide data on production levels of livestock enterprises, the amount of inputs used, the prices paid for inputs, and the costs and returns of (animals in) individual enterprises. Records can also be summarized to indicate the costs and returns on a monthly basis. The data can be used for developing both short-run and long-run plans for animal health management. The data are unique to the individual business. Farm and enterprise planning typically requires that the data available from previous years be supplemented with additional data on expected prices, input requirements and production levels for some possible decisions. Nevertheless, the data available from the past provide a starting point for the planning procedure (Boehlje & Eidman, 1984).
Farm managers develop, on their own or together with their veterinarian or extension worker, operational (short-term), tactical (medium-term), and strategic (long-term) plans (Figure 3.1), which usually include animal health plans. After such plans have been developed, the managers are concerned with implementing them, with monitoring and controlling the actual outcome over time, and with making adjustments in the plan if conditions change. In this way farm management is considered a **cyclical process**, as is outlined in Figure 3.1 (Huirne, 1990).

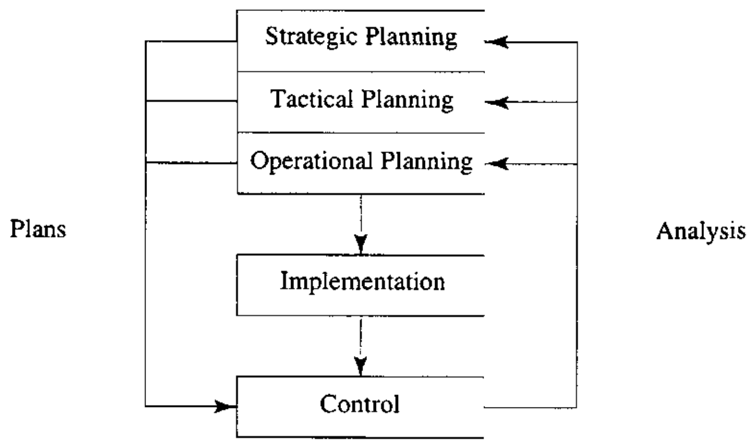


Figure 3.1 The management cycle

In developing plans for the enterprise, the farmer sets physical and financial standards of performance. Accounting systems can be developed to record data on the physical and financial performance measures that have been set for the enterprise. These data provide the farmer with an opportunity to compare the actual outcome with the performance standards (Huirne *et al.*, 1992). It is not unusual to set standards that are financial in nature. Farmers prepare projected costs and returns on a, for instance, monthly basis for the coming year and compare the actual costs and returns with the projections that have been made.

When a significant difference between planned and actual costs or returns occurs, this will immediately be clear to the farmer. This gives farmers the opportunity to take corrective actions before a serious economic problem can develop. In the development of longer-term plans, standards are set at the rate of return on investment and the rate of return on equity capital on a yearly basis (Boehlje & Eidman, 1984).

3.3 Enterprise budgets in gross margin form

Most farmers are in business to make a profit. The simplest and quickest method of calculating farm profit is to work out a budget along the lines of conventional costs and returns. This can be valuable because it can serve as an initial test of farm profitability. It omits so many details, however, that it is virtually useless for more accurate control. The biggest shortcoming of this approach is that it treats the business as a single, homogeneous unit, whereas most farm businesses can be seen as combinations of enterprises. An enterprise is a division of the business, usually identified by the type of product (Warren, 1986), for example, crops, swine and dairy herd. In planning and controlling the business, it is vital to be able to monitor each of the enterprises individually.

For the purposes above, a method of budgeting for profit which provides details on enterprises but bypasses the difficulties of allocating overhead costs is required. It must also avoid confusion between those costs which vary as a result of a change in the enterprise, and those which do not. One such method is preparation of budgets in **gross margin** form.

With this method, only certain costs are allocated to individual enterprises, the so-called **variable costs**. A variable cost is a cost that satisfies the following criteria (Warren, 1986): (1) it tends to vary directly with small changes in the size of the enterprise, and (2) it can relatively easily be allocated to a specific enterprise. Any cost which does not satisfy both of these criteria is termed a **fixed cost**. Usually no attempt is made to divide such a cost among the various enterprises.

Table 3.1 Examples of variable and fixed costs

Variable costs	Fixed costs
Veterinary services and AI	Regular labour
Feedstuffs (including forage)	Power and machinery running costs
Fertilizers	(except contract hire)
Seeds	Machinery and building depreciation
Sprays	Rent and/or landowning costs
Casual labour	Interest charges
Contract hire of machinery	

The costs of veterinary services and artificial insemination (AI) can easily be allocated to a dairy herd enterprise, and will vary with small changes in the size of the enterprise. That is why they are called variable costs. The cost of diesel fuel used in drilling wheat, for instance, will vary with enterprise size, but will be difficult to allocate without very detailed recordings (machines are used in other enterprises as well). It is thus classified as a fixed cost. A list of assorted variable and fixed costs is shown in Table 3.1.

A profit budget in gross margin form is built up as follows: for each enterprise, variable costs are deducted from enterprise output to give the enterprise gross margin. The gross margins of the various enterprises are added to give a total gross margin. From this the fixed costs of the entire business are deducted, resulting in the net profit for the business as a whole (see Figure 3.2).

Enterprise 1	**Enterprise 2**	**Enterprise 3**
Output	*Output*	*Output*
minus	minus	minus
Variable costs	*Variable costs*	*Variable costs*
equals	equals	equals
Enterprise gross margin	*Enterprise gross margin*	*Enterprise gross margin*

Total gross margin
minus
Total fixed costs
equals
Net profit of entire business

Figure 3.2 Profit budget in gross margin form (derived from Warren, 1986)

3.4 Partial budgeting

If the proposed analysis concerns a simple economic comparison of disease control measures on a farm, and the outcome does not involve a specific time pattern nor a high degree of uncertainty, then partial budgeting is the method of choice. Partial budgeting is simply a quantification of the economic consequences of a specific change in farm procedure, eg, a herd health program. It is closely related to the enterprise budget in gross margin form described in the previous section. Partial budgets are used to estimate the **change** that will occur in farm and enterprise profit from some change in the farm or enterprise plan by considering only those items of returns and costs that change. Partial budgets do not calculate the total income and the total expense for each of the plans, but list only those items of returns and expenses that change to estimate the difference in profit expected from the plans.

Partial budgeting is particularly useful for analysing relatively small changes in the business such as considering a shift in the replacement policy of dairy cows or a new breeding method (ie, artificial insemination), or when participating in a certain herd health program. The general format for a partial budget is made up of four sections: (1) **additional returns**: a list of items of returns from the alternate plan that will not be received from the base plan, (2) **reduced costs**: a list of items of costs for the base plan that will be avoided with the alternate plan, (3) **returns foregone**: a list of items of returns from the base plan that will not be received from the alternate plan, and (4) **extra costs**: a list of items of costs of the alternate plan that are not required with the base plan. To use the four sections in a consistent manner, the user of the partial budgeting procedure must first select one plan (for instance, the current one) as the basis for comparison, and the other as the alternative (proposed change). The change should be adopted if the sum of (1) and (2) is greater than that of (3) and (4).

As an example data were used to quantify the economics of caesarean section for a dairy cow. When represented in a partial budgeting format they are as follows:

1. Additional returns result from heavier weights of calves: US$25
2. Reduced costs include that less feed is required because of the drop in milk production: US$10
3. Returns foregone result from the drop in milk production: US$30
4. Extra costs include cost of surgery and an increase in culling rate: US$160

The net result (sum of (1) and (2) = US$35 minus sum of (3) and (4) = US$190) is negative: US$ -155. This means that caesarean sections as such are not desirable from an economic point of view. Should the calf (or cow) die otherwise, then its value should be included as additional returns.

As with other models, it is not always possible to identify clearly the returns and costs associated with the change in question. Many decisions may be rejected or accepted based on other criteria. Furthermore, special attention should be paid to the question whether it fits into the total farm or enterprise strategy.

The term partial budgeting does not imply that fewer details are required than for a total enterprise budget. This is not the difference between the two methods of budgeting; the difference is the impact of the proposed change on the farm organization. If the proposed change will affect the entire enterprise (or even the whole farm business), a total enterprise budget is needed. The partial budget is appropriate when some of the returns and costs will remain constant; it involves identifying those returns and costs that will change and the degree or amount of change.

Exercise

The example on caesarean section mentioned before in this chapter is worked out in more detail in the computer exercise given in Chapter 19. In this exercise you have to calculate the values of the different sections of a partial budget one by one, and use these to draw a conclusion. You will go through a sensitivity analysis to determine how stable your conclusions are. This exercise takes about 30 minutes.

3.5 Cost-benefit analysis

If the subject of research deals with more long-term disease control programs at regional or national level, then cost-benefit analysis is typically the analytical structure of choice. Cost-benefit analysis is a procedure for determining the profitability of programs over an extended period of time, ie, sufficiently long so that addition of an extra year does not materially influence the comparative ranking. There are three main elements involved: (1) enumeration of benefits (returns) and costs, (2) determination of the appropriate discount rate, and (3) specification of a decision criterion.

When the effects of a program have been estimated in physical terms, such as a decrease in production because of a disease, these effects must be translated into economic terms. Since the time at which costs or benefits occur generally differs between programs or alternatives, it is important that these future costs and benefits are 'discounted' to make them completely comparable, which results in the **present value** of costs and benefits. This is due to the time preference of money. A benefit of US$100 to be received in one year has less value today than a benefit of US$100 received immediately, because of (potential) interest yields. The formula used to calculate the Present Value (PV) of a future cost or benefit (FV), where r is the annual 'interest rate' (in %) and n is the number of years in the future is:

$$PV = FV / (1 + r/100)^n$$

The 'interest rate' used in cost-benefit analysis is called the **discount rate**, since it makes future values smaller than present values. The higher the discount rate, the more a program with high initial costs and a low level of benefits over a long period of time will be penalized. Conventionally, the discount rate does not allow for inflation of prices, and future prices are calculated at current prices rather than inflation-adjusted prices. This avoids the difficulty of predicting future inflation rates, which would in any case have no effect on the real rate of return from the program under consideration. This discount rate used is therefore the so-called 'real rate of interest', being the difference between the market rate of interest and the inflation rate. For example, if the market rate of interest is 9% and the inflation rate is 4%, the real rate of interest is 5%.

After having calculated the - expected - flow of costs and benefits resulting from the program and allowing for the time at which they occur, a **decision criterion** must be used to make a decision. An overall measure of value is required. Three such measures are commonly used, each of which has specific advantages and disadvantages:

1. **Net Present Value** (NPV), which expresses the difference between the total present value of benefits and costs (present value of net benefits). It represents the value of the program at today's prices. It indicates the scale of the net benefits, but does not show the relative size of the benefits and costs. Expensive programs will tend to have a high NPV, even if the benefits are only a few percentage points more than the costs. An NPV of US$100 000 from US$10 million benefits and US$9.9 million costs is quite different from the same NPV from US$1 million benefits and US$0.9 million costs.

2. **Benefit-Cost Ratio** (B/C ratio), which is calculated by dividing the total present value of the benefits by the total present value of the costs. It represents the relative size of the costs and benefits. It gives no indication, however, of the scale of investment, which should be considered if alternative projects are compared. Following the example under number 1, the B/C ratios are US$10 million / 9.9 million = 1.01 and US$1 million / 0.9 million = 1.11 respectively.
3. **Internal Rate of Return** (IRR), which reflects the interest rate which would make the total present value of the benefits equal to that of the costs; in other words, the interest rate which would have to be charged to reduce the net present value to zero. This measure is useful because it is easily comparable with (real) interest rates in alternative applications, and because it avoids the necessity of selecting a discount rate. The main disadvantage is that there is no simple formula, and it can only be calculated by trying different rates until the correct one is found. In some cases, there is no rate that will satisfy the condition, for example, if the annual costs never exceed the annual benefits.

The following example is to illustrate the cost-benefit approach for a vaccination program (Table 3.2). The monetary values are in millions of US$ and the annual real interest rate equals 5%. The NPV of this program turns out to be US$-1.2m (46.8 - 48.0), hence a negative NPV (while the undiscounted benefits exceed the undiscounted costs). The B/C ratio is 0.975 (46.8/48.0), slightly below the required minimum value of one. Finally, the IRR can be calculated by iteration as about 3.7%.

Table 3.2 Application of cost-benefit analysis

	Discount	Undiscounted		Discounted	
Year	factor	Costs	Benefits	Costs	Benefits
1	0.95[a]	27	0	25.7[b]	0.0
2	0.91	15	10	13.7	9.1
3	0.86	10	20	8.6	17.2
4	0.82	0	25	0.0	20.5
total		52	55	48.0	46.8

a $0.95 = 1 / (1 + 5/100)^1$
b $25.7 = 0.95 \times 27$

One variant of cost-benefit analysis is **cost-effectiveness analysis**, to be used when the expected benefits are excessively difficult to quantify. It is aimed at producing the desired result at minimum discounted cost. For example, an extension program may be evaluated by looking at how many people adopted the new technology. Preférence is given to a program that, given its costs, will benefit the largest number within the target population.

Some benefits and costs may, however, be difficult to quantify, even in physical terms. The satisfaction of having a healthy herd, reducing animal suffering and human health risks, and minimising the environmental damage caused by use of chemicals against insect parasites are some examples of such benefits and costs. Although it may not be possible to include these effects in an economic comparison, it is important that they are taken into account by decision makers. Despite the fact that some costs and benefits cannot be quantified, a cost-benefit analysis is useful in situations in which there are two or more ways of achieving a given objective.

Exercise

Do the computer exercise on cost-benefit analysis in Chapter 19. With this model you can practise how to calculate the discount factor to determine the present value of future costs and benefits. This is done with an example of enzootic bovine leucosis. After the calculation of the present values, you have to use different decision criteria (ie, NPV, B/C ratio and IRR) to draw your conclusion. Subsequently, a calculation is done with a different interest rate. This exercise takes about 40 minutes.

3.6 Decision analysis

If there are multiple possible outcomes of the proposed courses of action and chance is an important factor in determining which outcome occurs, then decision analysis is the approach of choice. 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. It is commonly thought to include four techniques (Gregory, 1988): (1) mathematical equations, (2) payoff matrices, (3) process diagrams or process flow charts, and (4) decision trees.

A **mathematical equation** is an approach that involves the presentation of data on the decision options, states of nature, probabilities and outcomes in a mathematical form (equation) and uses maximizing or optimizing criteria in selecting the action that represents the decision maker's preference. For example, to select among the decision options, A_1, A_2, ..., A_i, information may be presented in the following mathematical form:

$$A_i \quad = f\,(A_i, S_1, S_2, \ldots, S_j, P_1, P_2, \ldots, P_j, V_{i1}, V_{i2}, \ldots, V_{ij})$$

where

A_i = decision option (action);
S_j = state of nature;
P_j = probability of occurrence of state of nature (S_j); and
V_{ij} = value of outcome for each action and state of nature.

Assuming that one desires to use the expected monetary value (EMV) as the decision criterion (see below), then the EMV for each action (A_i) will be: $EMV(A_i) = \sum_j(P_j\ V_{ij})$, with the highest EMV being preferred.

As an example, assume that a farmer wants to know whether it is profitable or not to inseminate the sows twice during the same oestrus (24 hours after the first insemination) instead of once. So there are two options:

A_1 = inseminate once
A_2 = inseminate twice

After the insemination, the sow can be in two different states of nature:

S_1 = pregnant
S_2 = not pregnant

Assume further that eighty-three percent of the sows are pregnant after one insemination. This percentage increases to 86% when the farmer decides to inseminate twice during one oestrus. Finally assume that all the sows that do not conceive during this oestrus, will conceive the next time. The cost of delay of conception of one cycle is assumed to be US$50. The cost of insemination is US$4 per insemination. Now a mathematical equation can be used to calculate whether or not this second insemination is profitable. The selection criterion is the expected monetary value of the costs:

A_1 = *EMV* (inseminate once; pregnant, not pregnant; 0.83, 0.17; US$4, US$54)
A_2 = *EMV* (inseminate twice; pregnant, not pregnant; 0.86, 0.14; US$8, US$58)

Thus,
$$EMV(A_1) = \Sigma_j(P_jV_{1j}) = 0.83 \times 4 + 0.17 \times 54 = US\$12.50$$
$$EMV(A_2) = \Sigma_j(P_jV_{2j}) = 0.86 \times 8 + 0.14 \times 58 = US\$15.00$$

A_1, inseminating once, has the lowest EMV_{costs}, so the farmer should decide to inseminate only once per oestrus period. It is also possible to calculate the break-even point. This is the point where 'not profitable' changes to 'profitable', so $EMV(A_1)$ is equal to $EMV(A_2)$:

$$EMV(A_1) = 12.50 = EMV(A_2) = X \times 8 + (1-X) \times 58$$

where

X = proportion of sows pregnant after two inseminations during one oestrus

The solution of this equation is: X = 0.91. So at least 91% of the sows should become pregnant after two inseminations during one oestrus to make this strategy profitable.

A **payoff matrix** is a tabular presentation of data on the decision actions (as presented above) and provides a better visual presentation of the data. The presentation of data may take the form presented in Table 3.3.

Table 3.3 A payoff matrix

State of nature (S_j)	Value of outcome (V_{ij}) for different actions choices (A_i)				Probability of occurrence (P_j)
	A_1	A_2	....	A_i	
S_1	V_{11}	V_{21}	....	V_{i1}	P_1
S_2	V_{12}	V_{22}	....	V_{i2}	P_2
|	|	|		|	|
|	|	|		|	|
|	|	|		|	|
Sj	$V1j$	$V2j$	....	Vij	Pj

Using some decision criteria, a visual or mathematical computation is then made to select the preferred action.

A more concrete example of a payoff matrix is given below, in which three strategies A, B and C to control contagious disease outbreaks are distinguished. Total payoff (in millions of US$) of the strategies depends on the region of the outbreak under consideration, ie, North, South, East and West, as is summarized in Table 3.4.

Table 3.4 Example payoff matrix for contagious disease control

State of nature	Strategy A	Strategy B	Strategy C	Probability
Outbreak North	120	80	30	0.1
Outbreak South	110	70	60	0.5
Outbreak East	90	60	60	0.3
Outbreak West	40	50	60	0.1

A **process diagram** or **flow chart** is a technique in which the selection process is presented in a dynamic sequence of events, information flows, information processing steps and decision-making steps. This approach is used in computer programming and is gaining ground in diagnostic work and areas of artificial intelligence. An example is given in Figure 3.3. In diagnostic work, the different stages of the flow chart become the procedures that one goes through in identifying a specific disease. Thus by answering questions related to the symptoms of the disease and going through 'yes' and 'no' arrows, one ends up at a point where a particular disease is defined.

Decision-tree analysis is probably the most frequently used technique of decision analysis. A decision tree is defined as a graphical method of expressing, in chronological order, the alternative actions available to the decision maker and the choices determined by chance (Figure 3.4). The first step is to arrange the problems that must be solved and to characterize the information needed to translate the decision into a structure resembling a tree. In the decision tree, choices (A_i) such as whether or not to treat, are represented by squares called **decision nodes**. Chance events or states of nature (S_i), such as response to treatment, are

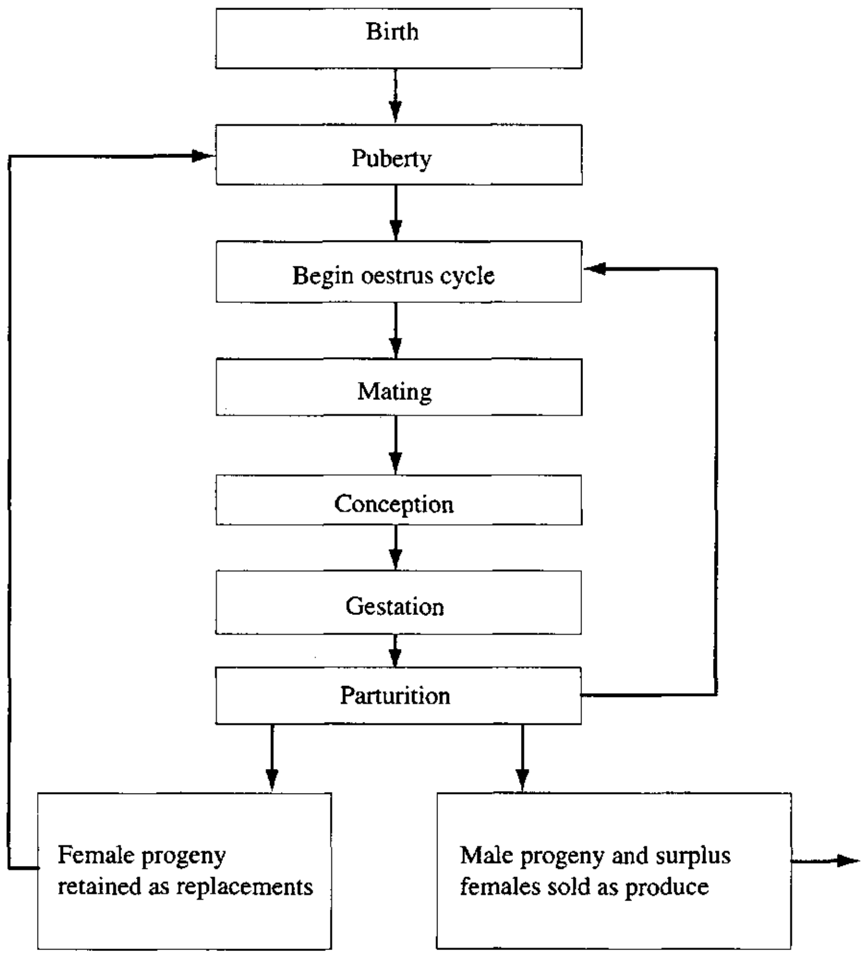


Figure 3.3 An example of a flowchart: the lifetime generator (Marsh, 1986)

represented by circles called **chance nodes**. Lines, or branches, follow each node and lead to the next event. The branches following each decision node must include all possible outcomes, and be mutually exhaustive.

After each chance node, there is a probability (P_i) that an event occurs. The probabilities following a chance node must add up to 1.00. These probabilities can be assessed from literature, experimental data or expert opinion. Expected outcomes (V_i), usually monetary, are entered at the far right of the tree branches. In Figure 3.4, the contagious disease example from Table 3.4 is presented in the form of a decision tree.

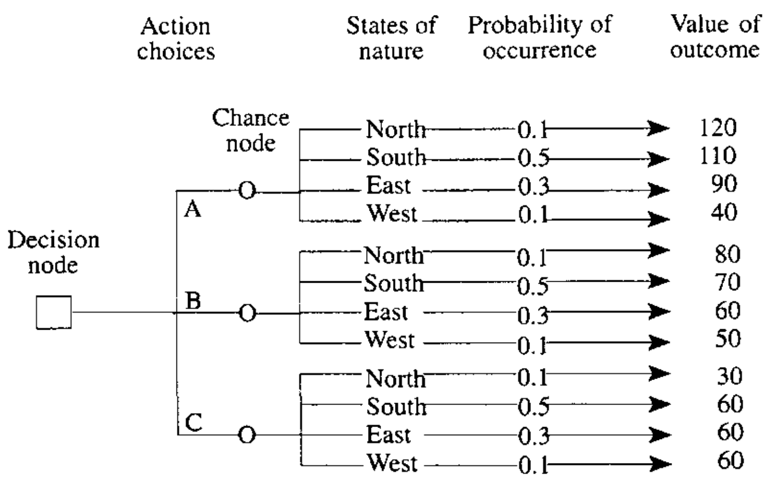


Figure 3.4 A hypothetical decision tree representing action choices (strategies A, B, C), states of nature (outbreaks in North, South, East and West), the associated probabilities and monetary values of outcome

The choice of preferred action is based on the decision criterion, eg, highest expected monetary value (EMV). The EMV criterion can be used to choose the decision (A_W) that maximizes the expected monetary value. This can be done as follows: $A_W = \max EMV(A_i) = \max \Sigma_j (P_j V_{ij})$. EMV(strategy A) = 0.1 x 120 + 0.5 x 110 + 0.3 x 90 + 0.1 x 40 = 98, EMV(strategy B) = 0.1 x 80 + 0.5 x 70 + 0.3 x 60 + 0.1 x 50 = 66, and EMV(strategy C) = 0.1 x 30 + 0.5 x 60 + 0.3 x 60 + 0.1 x 60 = 57. This means that strategy A has the highest EMV, and is the preferred one.

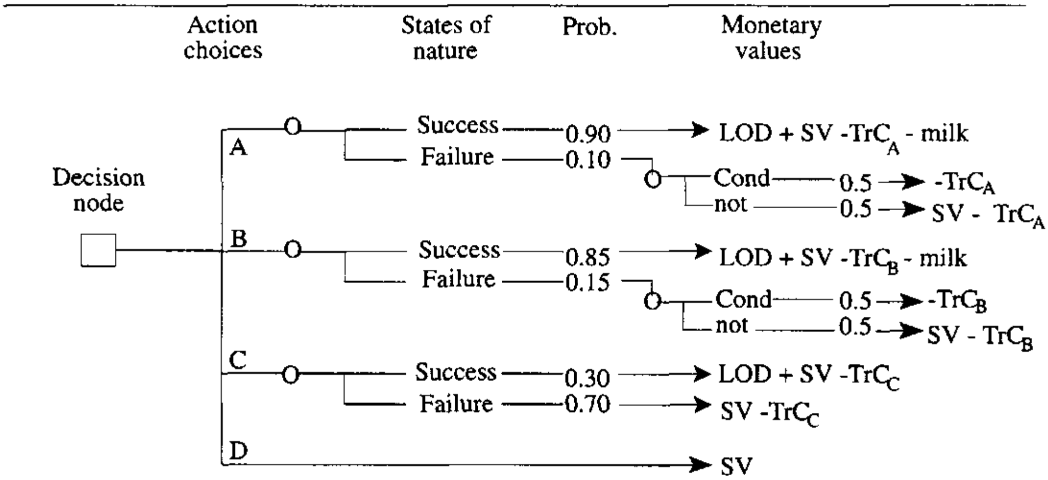
Another example deals with treatment of left-displaced abomasum, which primarily occurs in high-producing older dairy cows that have recently calved. Right-flank omentopexy, left-flank abomasopexy, and right-paramedian abomasopexy can all be used as treatments by skilled veterinarians with high degrees of success. The closed surgical techniques of blind stitch abomasopexy and the bar suture technique are only slightly less successful. A non-surgical method of rolling the cow to effect physical replacement of the abomasum has a high rate of recurrence of the condition and a lower rate of recovery, but this method may be preferred by farmers because it is noninvasive and inexpensive (Ruegg & Carpenter, 1989). Key question is: when are the losses minimal? Decision-tree analysis as a technique can help to make the choice. To construct the decision tree, the following assumptions are made, namely:

1. Surgery (right-flank omentopexy, etc.) costs the farmer US$215 and closed surgical techniques US$100. Rolling the cow costs US$60.
2. Losses in case of premature disposal occur when cows are replaced before reaching their economically optimal age. The extent of the losses highly depends on age and productive capacity of the cows concerned. For the cows in this example the corresponding losses are summarized in Table 3.5.

Table 3.5 Financial losses in case of disposal (US$)

	Relative production level (% at Mature Equivalent)			
	86-90%	98-102%	110-114%	122-126%
First lactation	72	439	833	1312
Fourth lactation	466	1003	1609	2296

3. In case of surgery, milk production is expected to be reduced by 750 kg, which corresponds to US$315 at a milk price of US$0.42 per kg. Taking into account a reduction in feed costs because of milk not produced (ie, 375 kg of concentrates at US$0.22 per kg) provides an expected net loss in milk receipts of US$315 - US$82.50 = US$232.50. In case of closed surgery, milk production is expected to be reduced by 375 kg, because this method is less invasive. No reduction is assumed in case of rolling the cow.
4. Cows have to be removed immediately, should surgery be unsuccessful. Meat is expected to be condemned because of antibiotics in 50% of the cases, losing the slaughter value of US$800.



Where
A = surgery;
B = closed surgical technique;
C = rolling the cow;
D = culling the cow immediately;

LOD = loss in case of disposal;
SV = slaughter value of the cow;
TrC_i = cost of treatment (with i = A, B or C);
milk = net loss in milk receipts;
Cond = meat is condemned because of antibiotics; and
not = meat is not condemned despite antibiotics.

Figure 3.5 Left-displaced abomasum decision tree

5. The recovery rate after surgery is 85%, and after closed surgical techniques this is 75%. Rolling has a recovery rate of 30%.

The tree shown in Figure 3.5 is based on these assumptions.
Evaluation of the decision tree is started by calculation of the expected monetary value (EMV) for each alternative. These values differ with the financial loss in case of disposal. The outcome is presented in Table 3.6. For each of the different production levels and lactation numbers, the best choice of action is underlined.
For first lactation cows of below-average production level, culling turns out to be the most profitable option. For an average first lactation cow and for an older cow of below-average production level rolling is the most profitable action. First lactation cows producing above average and older cows producing on average or better can best be treated by closed surgery. Surgery is the best option for older cows with a production level of 122 to 126%.

Table 3.6 Expected monetary values (US$) of the different action choices

Choice of action	**Relative production level (% at Mature Equivalent)**							
	86-90%		**98-102%**		**110-114%**		**122-126%**	
	Lac1	**Lac4**	**Lac1**	**Lac4**	**Lac1**	**Lac4**	**Lac1**	**Lac4**
Surgery	525	723	701	1180	1035	1695	1443	2279
Closed surgery	600	862	842	1265	1138	1720	1497	2235
Rolling	762	880	872	1041	990	1223	1134	1429
Culling	800	800	800	800	800	800	800	800

Table 3.6 shows that for an average-producing first lactation cow, the EMV of closed surgery is only slightly lower than the EMV of rolling the cow. A sensitivity analysis shows that with a recovery rate of 23% for rolling the cow instead of 30%, the EMVs of both actions would be equal. For an average-producing cow in lactation 4 the EMV of surgery would be equal to the EMV of closed surgery when the recovery rate of closed surgery equalled 68% instead of 75%. These sensitivity analyses show that the outcome of the calculations is highly dependent on the assumptions made.

Exercise

The example on left-displaced abomasum discussed above is worked out in more detail in the computer exercise in Chapter 19. This example is not built in a spreadsheet format, but in SMLTREE: a computer program especially useful for building decision trees (but not very user-friendly). You have to build the tree partly yourself, then you can evaluate the tree and do some sensitivity analyses on the effect of the producing level of the cow, the prices and the rate of success of the different strategies. This exercise takes approximately 45 minutes.

3.7 Concluding remarks

The basic methods described in this chapter include economic techniques that are relatively easy to understand and apply. Major advantage of these techniques is that they can be performed both by hand and by computer. Hand calculations are especially effective in practical situations (ie, in the field) when there is no computer available. Solving realistic problems by hand with more advanced and complex modelling techniques, such as dynamic programming, linear programming, Markov chains and Monte Carlo simulation (described in later chapters), is almost impossible. The basic techniques presented in this chapter, however, can also be modelled very well (within a reasonable period of time and without too much effort) in spreadsheet computer programs. This gives the decision maker the additional advantage to carry out a sensitivity analysis, in which input variables (assumptions) of the model are systematically varied over some range of interest to determine whether and how the outcomes change. Examples of input variable modifications are interest rates, future price and production levels and probability distributions. With the insights provided by the sensitivity analysis, the decision maker gets a better understanding of the problem in hand and of the effects of alternative actions that are available.

References

Boehlje, M.D. & Eidman, V.R., 1984. Farm management. John Wiley & Sons, New York, 806 pp.

Gregory, G., 1988. Decision analysis. Plenum, New York, 385 pp.

Huirne, R.B.M., 1990. Computerized management support for swine breeding farms. PhD-Thesis, Department of Farm Management, Wageningen Agricultural University, Wageningen, 165 pp.

Huirne, R.B.M., Dijkhuizen, A.A., Renkema, J.A. & Van Beek, P., 1992. Computerized analysis of individual sow-herd performance. American Journal of Agricultural Economics 74: 388-399.

Marsh, W.E., 1986. Economic decision making on health and management in live-stock herds: examining complex problems through computer simulation. PhD-Thesis, University of Minnesota, St. Paul, 304 pp.

Ruegg, P.L. & Carpenter, T.E., 1989. Decision-tree analysis of treatment alternatives for left-displaced abomasum. Journal of American Veterinary Medical Association 195: 464-467.

Warren, M.F., 1986. Financial management for farmers. Hutchinson, London, 306 pp.

4

Economic impact of common health and fertility problems

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Objectives

From this chapter the reader should gain knowledge of:

- the financial losses in dairy cattle owing to reproductive failure, mastitis and clinical digital disease
- the way to calculate the economic impact of number of litters per sow per year, litter size, feed conversion efficiency, daily weight gain and mortality rate on swine farms

4.1 Introduction

The calculation of **financial losses** is especially of importance to help provide a better overall view of the impact of disease and to contribute to estimating the extent of the losses to be avoided. The latter is particularly the case if a difference in losses among farms is indicated, in addition to the losses in the average situation. Three questions should be answered for an economic characterization of the actual situation:

1. To what extent does the problem in its various forms occur?
2. What are the quantitative and qualitative effects on production, mortality, etc. expressed in physical terms?
3. How can these physical effects be expressed in financial terms?

The accuracy of the answers to these questions - and thus of the economic calculations - highly depends on the availability and usefulness of the underlying data. But even if enough data are available, it is not a simple task to quantify the losses from disease, because their effects:

- are not always obvious and pronounced;
- are influenced by other factors such as nutrition and housing;
- have a temporal dimension which adds to the complexity of determining their impacts at different stages in time; and
- often manifest themselves together with other diseases.

This may help explain why the outcome of calculations often differs so much, even for similar farm and price conditions.
From a methodological point of view, financial losses at farm level can be attributed to one or more of the following factors at animal level:
a. less efficient production and higher veterinary costs prior to disposal;
b. reduced slaughter value and idle production factors at disposal; and
c. lost future income owing to disposal.

Factor c only occurs when animals have to be replaced before reaching their economically optimal age. The loss is the difference between (1) the income that a particular animal could yield during her 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 over the same period of time of replacement animals with normal productive qualities and normal probabilities of disposal. When calculating the total loss per farm, factors a, b and c must be added.
Quantifying the economic losses owing to disease is mainly performed by simple partial budgeting techniques. In the remainder part of this chapter this type of calculation is illustrated for dairy cattle (ie, reproductive failure, mastitis and lameness) and swine (sow and pig fattening performance) for typical Dutch conditions. The approach is general, however, and could also be used for other farm and price conditions.

4.2 Applications in dairy cattle

4.2.1 Reproductive failure

Underlying reasons for reduced reproductive performance in dairy herds may range from infertile cows to inadequate management practices. Economically speaking, such reasons eventually lead to either a **longer calving interval** or **premature disposal**. Hence, economic calculations should include both these factors.

Calving interval

The issues of optimal calving intervals and the effect of a change in calving interval (or days open) on the economic performance of cows have often been discussed. While some studies have found short intervals of 310 to 340 days to be optimal, others have indicated intermediate optima between 370 and 400 days. One reason for the different results in these studies may be the difference in criteria used (eg, milk production only versus a comparison on total net return) and the different price and production conditions under consideration. Also, in some field studies the average effect for all cows is presented, whereas others distinguish between cows that differ in age and calving season. Moreover, the losses because of extended calving intervals are sometimes wrongly combined with those from premature disposal, which also affects the results.
For a valid economic evaluation, insight is required into the relationship - on a per-cow basis - between the length of calving interval and the resulting **net return per unit of time** (day, year).

Taking a year as the most common basis in income calculations, total net return per calving interval (TNR_i) should be multiplied by $365/L_i$, where L_i refers to the length (in days) of the calving interval i concerned. The calving interval with the highest yearly net return ($Max[TNR_i \times 365/L_i]$) is defined as optimal, while the difference with every other calving interval indicates the loss in income per cow per year. These differences can only be influenced by those revenues and costs which are not proportional to the length of calving interval. Three categories are commonly considered (Jalvingh, 1993):

- net milk receipts;
- calf sales; and
- other components.

Each of these is discussed and illustrated for herd conditions as described in Appendix 4.1. Standard lactation curves of daily milk yields (kg) for individual cows have a downward slope following peak production. The increase in total lactation milk production with longer calving interval, therefore, is less than proportional. Total increase is further diminished by an increase in days dry with longer calving intervals. Moreover, pregnancy usually reduces milk yield beyond about four months after conception. As an example, results are presented in Table 4.1 for third lactation cows with average production level.

Table 4.1 Milk yield for third lactation cows

Calving interval (months)	**12**	**14**	**Difference**
Length of lactation (days)	305	345	+ 40
Length of dry period (days)	60	80	+ 20
Milk yield per lactation (kg)	7397	7979	+582
Milk yield per year (kg)	7397	6853	- 544

As indicated in Table 4.1, lactation length increases by 40 days and the dry period by 20 days with a calving interval that is two months longer. Total lactation milk yield increases by 582 kg, which equals 582/60 = 9.7 kg per additional day of calving interval. However, this increase is considerably less than the average production of 20.3 kg per day with a calving interval of 12 months. So, annual milk yield decreases by 544 kg (ie. 7.4%) or 544/60 = 9.1 kg per additional day of calving interval. At a milk price of US$0.42 per kg, therefore, the average loss amounts to US$3.82 per day. However, a considerable part of these losses is compensated for by three interrelated factors:

- higher percentage of fat and protein in the extra milk yield;
- lower total feed costs; and
- positive effect on milk yield in the subsequent lactation.

In contrast to the downward slope of the milk yield curve (kg), the percentages of fat and protein increase towards the end of lactation. Thus, the fat and protein percentages in the extra milk yield with lengthened calving interval are relatively high. This is an important consideration if the milk price is dependent on fat and protein contents (as is the case in many countries). Feed requirements per cow depend, among other things, on age, level of milk yield, percentages of fat and protein in the milk and live body weight. Consequently, total feed costs decrease with diminishing annual milk yield. On the other hand, feed costs increase with calving interval because of the increase in live body weight. Finally, the increased dry period and associated higher live body weight with longer calving interval is assumed to have a slightly positive effect on milk yield in the subsequent lactation. This leads to a difference in net milk receipts (calculated as the margin between gross milk receipts and feed costs), as is presented in Table 4.2.

Table 4.2 Losses in net milk receipts per cow per year (US$)[a]

Calving interval (months)	11	12	13	14	15	16	17
Lactation 1	21	0	13	42	81	123	169
Lactation 2	1	0	36	91	152	219	288
Lactation 3	0	17	72	144	223	307	393
Lactation 4-5	0	19	76	152	234	321	409
Lactation 6-8	0	20	77	152	233	319	408
Lactation ≥9	0	18	73	145	223	306	392
Average cow	0	3	43	101	167	237	309

[a] The calving interval with highest net milk receipts is set at zero

Taking into account net milk receipts only, the optimal calving interval for first lactation cows is one year. For older cows the optimal interval is shorter than one year, while the loss due to a longer calving interval is much higher than for first lactation cows.

It is obvious that the number of calves born per year will decrease with longer calving intervals. With a calving interval of 11 months, for instance, theoretically 12/11 = 1.09 calves are born per year versus 12/17 = 0.71 with a calving interval of 17 months. These differences are slightly reduced when taking into account a - fixed - percentage for calf mortality. Nevertheless, considering calf sales only, the shortest calving interval is optimal for both first lactation and older cows.

Labour costs per year will slightly decrease with longer calving intervals because of, for instance, fewer milking days and number of calves born. Other components to be included involve costs of insemination and veterinary treatment. Their relationship with the length of calving interval, however, highly depends on the underlying causes of the problems (eg, poor oestrus detection versus retained placenta and/or metritis). It is considered more appropriate, therefore, to exclude the costs of insemination and veterinary treatment from the more general type of calculations with respect to calving intervals as such and add them separately per farm as additional costs due to reproductive failure.

The final economic comparison of calving intervals should be based on the combined outcome of the three categories considered (net milk receipts, calf sales and other components). The results are summarized in Table 4.3.

Table 4.3. Optimal length of calving interval and calculated losses per cow per year (US$)

Calving interval (months)	11	12	13	14	15	16	17
Lactation 1	7	0	26	66	113	163	217
Lactation 2	0	17	68	136	208	284	362
Lactation 3	0	36	106	297	282	376	471
Lactation 4-5	0	38	111	199	293	390	487
Lactation 6-8	0	38	111	199	292	389	486
Lactation ≥9	0	36	106	192	282	375	470
Average cow	0	20	75	146	222	301	382
Per day longer calving interval for an average cow:							
Per average day	-	0.67	1.25	1.62	1.85	2.01	2.12
Per marginal day	-	0.67	1.83	2.37	2.53	2.63	2.70

If all relevant factors are considered, the optimal calving interval for first lactation cows is still exactly one year. For older cows the optimal interval is shorter than one year, while the loss due to a longer calving interval is much higher than for first lactation cows. For an average cow it is also apparent that the **average loss per day** increases from US$0.67 (20/30) with a calving interval of one year to US$2.12 (382/180) with a calving interval of 17 months. Thus, the costs of each day of increased calving interval are not uniform, which is also shown by the **marginal loss per day**. Lengthening the optimal calving interval by one month causes a loss of US$0.67 ((20-0)/30) per day, which increases to US$1.83 ((75-20)/30) per day when lengthening from 12 to 13 months, while the loss due to a further lengthening amounts to US$2.37 to 2.70 per extra day.

The outcome of the calculations on the economics of calving interval is found to be not very sensitive to changes in major input factors such as milk price, value of calves, production level and production effect in subsequent lactations. In contrast, a change in shape of the lactation curve has a very strong influence. A 10% higher **persistency** (ie, a reduced downward slope after peak production) leads to a decrease of 25 to 50% in loss, with the optimal interval increasing from 11 to 12 months. A 10% lower persistency increases the loss by 25 to 50%: then the marginal loss beyond 400 days amounts to almost US$3.50 per day. **Month of calving** is another factor with a significant impact on the economics of calving interval, at least if prices for milk and calves show seasonality. For Dutch conditions these prices are highest in autumn and winter. Losses because of extended calving intervals, therefore, are higher for cows calving in these seasons than for cows calving in spring and summer, as is shown in Table 4.4. In the latter cases the time of calving(s) is shifting towards a more profitable season.

Table 4.4 Optimal length of calving interval and calculated losses per cow per year (US$) for an average cow with different months of calving[a]

Calving interval (months)	11	12	13	14	15	16	17
Month of calving							
- February	0	48	120	158	194	271	347
- May	10	0	57	128	197	239	285
- August	0	8	23	58	146	281	407
- November	0	32	141	258	365	468	519

[a] Assuming subsequent calving intervals to be 12 months

Premature disposal

The annual culling rate on commercial dairy farms is, on average, about 30 to 35%, nearly one quarter of which is due to reproductive failure. In quantifying the losses owing to premature disposal, special attention has to be paid to factors associated with age (eg, milk receipts, value of calves, slaughter value of cows, feed costs and probabilities of disposal) and to the costs of replacement heifers[1]. The extent of these losses is strongly influenced by the age and relative production level of the cow under consideration, ranging from about US$60 for low-producing cows (80-85% at Mature Equivalent) to more than US$1400 for high-producing young cows (about 125% at Mature Equivalent). The average loss per cow culled owing to reproductive failure was determined to be US$220 to 280, which is much lower than disposal for several other reasons. This is because these cows can finish their final lactation in a normal way and their slaughter value remains high.

Total reproductive losses per farm

Assuming a typical Dutch herd with an average calving interval of about 380 days (Appendix 4.1), the distribution of cows over the various classes of calving intervals considered in Table 4.3 is 36%, 28%, 17%, 10%, 5%, 3% and 2% respectively. Taking into account the calculated losses for an average cow, total annual losses of the 380-day herd calving interval average 0.36 x 0 + 0.28 x 20 + ... + 0.02 x 382 = US$61 per cow. About 80% of the cows calve in a year, making the losses on herd basis equal to 0.80 x US$61 = US$49 per cow per year. Moreover, 6 to 7% of all cows are culled because of reproductive failure, resulting in a total loss of USS16 per cow per year (ie, 0.06 to 0.07 multiplied by US$220 to 280). Finally, some other costs will turn up, depending on the cause(s) of the problems (eg, additional costs of insemination and veterinary services). So, in total the annual costs of reproductive failure will average about US$80 per cow per year, or US$3600 for a 45-cow herd. This corresponds to 2% of gross return and 10% of the farmer's net return to labour and management (Appendix 4.1).

[1] The methodology underlying these calculations is explained in Chapter 7.

4.2.2 Mastitis

Mastitis is generally considered a disease of major economic importance in dairy cows. In the literature, the outcome of calculations of losses attributed to mastitis differ considerably, depending on the method used, the sources of losses included and the origin of the data. Consequently, those results should be interpreted with care.

Most frequently, economic calculations on mastitis losses are based on annual herd parameters rather than on daily cow performances. Previously, the number of somatic cells in milk was used as a major criterion for estimating the presence and severity of mastitis. There is an on-going discussion, however, whether this criterion is still appropriate. Using **pathogens** in milk as a diagnostic criterion seems to be more preferable. Four different types of pathogens are especially of importance to be considered: coliform, streptococcal, staphylococcal and *Corynebacterium pyogenes*. Additionally, there may be clinical cases in which no pathogens can be detected, usually defined as bacteriologically negative.

The economic effects of mastitis can be divided into three categories (Houben, 1995):

- reduced milk receipts;
- cost of treatment; and
- premature disposal.

No single set of published data is available to quantify these effects. Therefore, they have to be derived from various sources. These data are summarized in Table 4.5 for Dutch conditions, and focus on so-called clinical mastitis.

Table 4.5 Major input data for infections with clinical signs

Type of pathogen	Frequency[a]	Infected quarters per case	Annual milk decrease per quarter (%)	Annual culling rate(%)
Streptococcal	10.8	1.3	22	10
Coliform	7.0	1.1	17	14
Staphylococcal	3.0	1.4	26	14
C. Pyogenes	1.6	1.1	48[b]	80
Bact. Negative	5.6	1.3	21	12
Total/Average	28.0	1.3	23	14

[a] Percentage cow cases per year
[b] Next lactation

As shown in Table 4.5, the total frequency of **clinical mastitis** is estimated to average 28 cow cases per 100 cows per year, with 28 x 1.3 = 36 quarters being involved. Streptococcal infections appear to be the most frequent. The estimated decrease in total milk production is taken to be 23%, ranging from 17% for coliform to 48% for *Corynebacterium pyogenes*.

Fat content of milk is assumed to be reduced by over 4%. For each kg of milk not produced a saving of 0.5 kg of concentrates is taken into account. Treatment costs are considered to include veterinary fees, drug expenses and farmer's labour. Milk from cows treated with antibiotics will not be delivered to the factory for five days, but fed to young calves.This reduces the losses from otherwise discarded milk. Table 4.5 shows that, on average, 14% of the cows with clinical mastitis are culled. *Corynebacterium pyogenes* ranks by far the highest with a culling rate of 80%. The average loss per cow culled owing to mastitis is assumed to be about US$250, which equals the loss per cow culled for reproductive failure. Finally, per year five cows (ie, six quarters) in a 45-cow herd have infections **without any clinical signs**, 60% of which are caused by streptococcal and 40% by staphylococcal bacteria. Losses are restricted to milk reduction (4.6% per lactation) and fat reduction (1.9% per lactation). Mastitis without clinical signs is difficult to detect. Therefore, neither treatment costs nor premature disposal are included in the calculations. The calculated annual losses owing to mastitis, based on all these assumptions, are summarized in Table 4.6.

Table 4.6 Calculated annual losses due to mastitis (US$)

Type of pathogen	Per infected cow: With clin. signs	Per infected cow: Without clin. signs	Total per average cow in herd
Streptococcal	296	25	35 (40%)
Coliform	240	-	17 (19%)
Staphylococcal	337	41	14 (16%)
C. Pyogenes	349	-	6 (7%)
Bact. Negative	284	-	16 (18%)
Total/Average	517	57	88 (100%)

Per clinically infected cow, the *Corynebacterium pyogenes* pathogen causes the highest losses, especially because of its extremely high culling rate. Staphylococcal infections rank second, due to a combination of a relatively high number of infected quarters per case and a considerable loss in production. Infections without any clinical signs are, from an economic point of view, far less important. At farm level streptococcal infections have the greatest economic impact, ie, 40% of total losses, while *Corynebacterium pyogenes* ranks lowest. The differences in costs per case are offset by differences in frequency rates. Total losses per farm average US$88 per cow per year (or about US$4000 for a 45-cow herd), which equals approximately 11% of farmer's net return to labour and management (Appendix 4.1). Reduction in milk and fat production accounts for 70% of these losses, 18% of which owing to treatment and 12% caused by premature disposal.

4.2.3 Clinical digital diseases

Calculations on the economics of lameness in dairy cattle are sparse, because there is a serious lack of data on both frequency and effects of the disease. Available research for the Netherlands shows that in 21% of the lactations one or more cases of clinical digital diseases are diagnosed. Twenty-eight percent of the affected cows are replaced, which make up 7.6% of all cows culled. Losses are expected to include:

- reduced milk receipts;
- longer calving interval;
- treatment costs;
- extra labour input by the farmer;
- premature disposal; and
- reduced - energy - efficiency due to weight fluctuations.

Reduction in milk yield turns out to be limited, but varies highly between cows that are not culled and cows that are culled because of digital diseases. Culled cows have considerably and significantly lower milk, fat and protein productions (Table 4.7).

Table 4.7 Production data and calving intervals of cows with clinical digital diseases, divided into cows culled and not culled

	Loss of production (in %)			Longer calving
	milk (kg)	fat (kg)	protein (kg)	interval (days)
cows culled	11.3%	14.1%	16.3%	—
cows not culled	0.8%	1.1%	1.1%	9.0

It is also shown in Table 4.7 that cows with digital diseases have on average a 9-day longer calving interval: 385.5 days compared with 376.5 days for cows without digital diseases.

Considering treatment costs, it is known that 60% of the cows with clinical digital diseases receive veterinary treatment. Farmer's additional labour input required for cows with this type of problems is estimated to be slightly more than 30 minutes per lactation. Assuming that this time could have been used alternatively, opportunity costs are taken into account in the calculation of the losses.

Losses due to premature disposal consist of loss of slaughter weight and carcass quality, loss of future income and losses associated with idle production factors. The way these losses are calculated is discussed in detail in Chapter 7.

Quite often, lameness results in loss of body condition, because the cow is not able to take in the required amount of energy for maintenance and production. This loss of live weight of cows with clinical digital diseases amounts to 3 to 5% of the total live weight. Moreover, the maintenance requirement may be increased due to immune responses.

Combining these assumptions provides an estimate of the losses, as summarized in Table 4.8. Total losses amount to almost US$30 per cow per year, ranking third after mastitis and reproductive failure.

Table 4.8 Average annual losses owing to clinical digital diseases (US$)

	Per case	Per cow present in herd
Reduced milk receipts	36	8
Longer calving interval	16	3
Treatment costs	12	3
Extra labour input by the farmer	17	4
Premature disposal	45	9
Weight fluctuations	1	-
Total	127	27

4.2.4 Total losses and differences among farms

Total calculated losses owing to reproductive failure, mastitis and lameness average US$80 + 88 + 27 = US$195 per cow per year. Considering other diseases not yet included, total losses in dairy cattle may increase to - at least - US$300 per cow per year on average. This corresponds to almost 10% of gross return and 40% of farmer's net return to labour and management (Appendix 4.1).

It will not be possible - and profitable - to avoid all calculated losses. Differences among farms can help to gain insight into what is attainable under current conditions. Farm-specific data suitable for research on animal health economics are sparse, however. Available data on differences in calving interval suggest big differences among farms, easily exceeding the calculated average loss. Moreover, the best 20% of farms prove to realize only half of the calculated losses on the average farm. So, there is reason to expect that considerable economic improvement can be achieved, especially for farms with higher than average losses.

4.3 Applications in swine

4.3.1 Sow performance

Differences among farms

Available data on health and fertility problems in swine are too fragmental to be included in economic calculations. Another way to gain more insight into their - potential - economic impact is to analyse differences in productive performance among farms, the data of which are more readily available. In the Netherlands, for instance, sow herds with the best performances raise more than 23.4 pigs per sow per year, while the 20% with the poorest results do not exceed 17.8 pigs (Table 4.9). Assuming an average net economic value of roughly US$45 for each additional pig raised, such a difference corresponds with US$252 per sow per year, which is even more than the average net return to labour and management on a typical farm (Appendix 4.2).

Table 4.9 Differences in performance among Dutch sow herds

Performance indicator	Five classes with 20% of farms in each Worst	Poor	Average	Good	Excellent
Litters per sow per year	<2.14	2.14-2.19	2.20-2.24	2.25-2.34	>2.34
Pigs born alive per litter	<10.4	10.4-10.6	10.7-10.9	11.0-11.2	>11.2
Pig mortality rate	>16.5	16.5-14.6	14.5-12.6	12.5-10.6	<10.6
Pigs raised per litter	<8.4	8.4-9.0	9.1-9.5	9.6-10.0	>10.0
Pigs raised per sow per year	<17.8	17.8-19.6	19.7-21.5	21.6-23.4	>23.4

It is not known, however, what portion of these differences is directly related to health and fertility problems in a strict sense. Assuming these problems to be responsible for half the difference would imply an impact equal to 10% of gross return and 50% of farmer's net return to labour and management. Such values are not unlikely when compared with dairy cattle. The economic weights for single performance indicators will now further be determined and explained, using the partial budgeting technique.

Number of litters per sow per year

If conception is delayed by one cycle (21 days), income that could otherwise have been obtained over the course of a year will be obtained over 386 days (365 + 21 days). Annual performance as indicated in Appendix 4.2 will then be 365/386 x 2.22 = 2.10 litters and 365/386 x 20.6 = 19.5 pigs raised per sow per year, which means a reduction of 0.12 litters and 1.1 pigs respectively. The resulting losses because of a 3-week delay in conception include (Jalvingh, 1993):

Revenues foregone

- 1.1 pig x US$64 = US$70.40

Reduced costs

- Feed for the sow

The allocation of time to gestation, lactation and days open per sow per year changes with a delay in conception from 255 (2.22 x 115), 67 (2.22 x 30) and 43 (365 - others) to 242, 63 and 60 respectively. Assuming a common feeding scheme this results in a saving of about 15 kg x US$0.24 = US$3.60.

- Feed for the pigs

1.1 pig x 30 kg x US$0.40 = US$13.20.

- Others

There are hardly any other savings, except for transportation and (medical) treatments, estimated at US$4.00 x 1.1 piglet = US$4.40.

Net result

- Total revenues foregone minus reduced costs equal US$70.40 - (US$3.60 + 13.20 + 4.40) = US$49 per three weeks of delay in conception, or slightly more than US$2 per extra day open.

A shortening of the interval between weaning and conception by three weeks increases the annual results presented in Appendix 4.2 to 365/344 x 2.22 = 2.36 litters (plus 0.14) and 365/344 x 20.6 = 21.9 pigs raised per sow per year (plus 1.3). Such an increase implies an extra profit of about US$58 per three weeks of earlier conception, or about US$2.75 per - avoided - day open. So, other than with dairy cattle, the cost per additional day open in sows decreases with longer intervals.
Taking into account the difference between the best performing farms realizing more than 2.34 litters per sow per year and the worst performing ones with fewer than 2.14 litters (Table 4.9) implies a difference in income of approximately US$90 per sow per year or even 37% of a farmer's typical income (Appendix 4.2).

Litter size

Calculating the economic value of one additional pig raised per sow per year includes:

Additional revenue

- 1 pig x US$64 = US$64

Additional costs

- Feed for the sow: 30 days x 0.4 kg = 12 kg x US$0.24 = US$2.88
- Feed for the pig: 30 kg x US$0.40 = US$12.00
- Others: transportation, (medical) treatment etc. = US$4.00

Net result

- The additional revenue minus costs equals about US$64 - (US$2.88 + 12.00 + 4.00) = US$45 per pig raised.

The same approach can be used when calculating the economic value of one additional pig born alive, but then the probability of survival should be taken into account. On average, total pig mortality equals about 14% (Table 4.9) implying a survival rate of 86%. Given that the majority of pig deaths occur within the first few days of life, the economic value of one additional pig born alive is US$45 x 0.86 = USS39. The lower the survival rate, the lower the economic value. This may especially be true with increasing litter size.
The 20% of farms with the best and those with the worst results differ at least 0.8 pig born

alive and 1.6 pig raised per litter, as indicated in Table 4.9. With 2.22 litters per sow per year and an economic value of US$39 and US$45 per pig respectively, the differences in income caused by these factors equal US$70 to US$160 per sow per year. This is even 30 to 65% of a farmer's typical income (Appendix 4.2).

Premature disposal

In the Netherlands about 45% of the sows are replaced annually. The average productive lifespan of the sows, therefore, is 100/45 = 2.2 years or about 5 litters only. Reproductive problems are the major reasons for disposal (35%), with failure to conceive as its major component. Low productivity is the second most important reason (17%), together accounting for more than half of the annual culling rate.

Increasing the herd life is economically attractive, because (1) fewer replacements have to be bought or raised, and (2) more sows will reach the most productive parity numbers 4 to 8 (Huirne, 1990; Jalvingh, 1993). Dynamic programming was used (explained in Chapter 7) to quantify the profitability of increased herd life. Results are summarized in Table 4.10.

Table 4.10 Average profitability of herd life in sows

	+1 litter	Herd average	-1 litter
Litters per total sow life	6.1	5.1	4.1
Annual replacement rate	38.2	45.6	56.7
Litters per sow per year	2.31	2.31	2.31
Pigs raised per sow per year	21.0	20.8	20.6
Pigs raised per total sow life	55.3	46.0	36.6
Income margin/sow/year (US$)	481 (+16)	465	442 (-23)

Table 4.10 shows that income per sow per year increases by US$16 if the average age at culling is increased by one litter. One litter less decreases income by more than US$20, indicating that a reduction of the risk of removal is subject to diminishing additional returns. Assuming a difference in average herd life of two years between the 20% of farms with the best and those with the worst results would - according to Table 4.10 - cause a difference in income per sow per year of about US$40, or 16% of a farmer's typical income (Appendix 4.2).

4.3.2 Pig fattening performance

Differences among farms

The economic performance on pig fattening farms is highly influenced by feed conversion efficiency, daily weight gain and mortality rate. Differences in these parameters among farms are summarized in Table 4.11.

Table 4.11 Differences in performance among Dutch pig fattening herds

Performance indicator	Five classes with 20% of farms in each: Worst	Poor	Average	Good	Excellent
Feed conversion effic. (kg feed/kg weight gain)	>2.99	2.99-2.92	2.91-2.84	2.83-2.76	<2.76
Daily weight gain (grams)	<681	681-699	700-730	731-755	>755
Mortality rate (%)	>3.65	3.65-3.06	3.06-2.54	2.53-1.56	<1.56

As with sow herds, it is not precisely known what part of these differences is directly related to health problems as such. But even if this is a minor part, the effect on income for a typical farm (Appendix 4.3) will still be considerable, as can be derived from the following economic calculations for the single performance indicators.

Feed conversion efficiency

A difference in feed conversion ratio (kg feed per kg of weight gain) of 0.1 affects feed consumption by 8.5 kg per hog sold and income by 8.5 kg x US$0.28 = US$2.38 per head. According to Table 4.11, the difference between the lower bound of the 20% best performing farms and the upper bound of the 20% of the worst performing farms equals 0.25 (3.0 minus 2.75) and, therefore, causes a calculated total difference in income of 0.25/0.1 x US$2.38 = US$5.95 per hog sold. Such a difference equals 3% of gross return and 66% of net return to labour and management on a typical fattening farm (Appendix 4.3).

Daily weight gain

In quantifying the economic impact of differences in daily weight gain, it is necessary to determine which single cost item (specified in Appendix 4.3) is related to the length of the fattening period, and which is not. Purchase price of the piglet and cost of transportation of the fattened hog are examples of costs which are **not** related in this way. Moreover, no relationship should be included for total feed costs, because differences in this parameter manifest themselves already in the feed conversion efficiency and thus should not be counted twice. The other cost items are more likely to be related to the length of the fattening period. So, the income margin per day of fattening period in the starting situation (Appendix 4.3) equals: gross return - (purchase price piglet + feed costs + cost of transportation) = US$178 - (US$64 + 69 + 3) = US$42 in 119 days or US$0.35 per day. A 10-gram increase in daily weight gain decreases the initial fattening period of Appendix 4.3 by 1.7 days, implying an economic value of 1.7 x US$0.35 = US$0.60. With a 10-gram decrease these values are the same. So, the economic value per gram of daily weight gain equals about US$0.06. Considering the upper and lower bounds of the 20% best and 20% worst performing farms (Table 4.11) this implies a difference in income of US$4.50 per hog sold. Such a difference equals about 3% of gross return and 50% of net return to labour and management on a typical fattening farm (Appendix 4.3), ranking second after feed conversion efficiency.

Mortality rate

Assuming that, on average, mortality occurs halfway the fattening period, the losses include:

- costs before death: purchase price piglet + 59.5/119 x (gross return - purchase price piglet) = US$64 + 0.5 x (US$178 - 64) = US$121; and
- return to labour and housing foregone after death: 59.5/119 x (housing + labour + net profit) = 0.5 x (US$20 + 10 - 1) = US$15.

So, in total, these costs average US$136 per dead fattening hog, or US$1.36 per percentage of hog mortality. For the corresponding differences between the highest and the lowest classes in Table 4.11 this implies a difference in income of 2.1% x US$1.36 = US$2.86 per hog sold. This difference equals almost 2% of gross return and 32% of net return to labour and management on a typical fattening farm (Appendix 4.3), ranking third after feed conversion efficiency and daily weight gain.

References

Houben, E.H.P., 1995. Economic optimization of decisions with respect to dairy cow health management. PhD-Thesis, Department of Farm Management, Wageningen Agricultural University, Wageningen, 146 pp.

Huirne, R.B.M., 1990. Computerized management support for swine breeding farms. PhD-Thesis, Department of Farm Management, Wageningen Agricultural University, Wageningen, 165 pp.

Jalvingh, A.W., 1993. Dynamic livestock modelling for on-farm decision support. PhD-Thesis, Department of Farm Management and Department of Animal Breeding, Wageningen Agricultural University, Wageningen, 164 pp.

Appendix 4.1 Typical results for commercial Dutch dairy farms

Herd size 45 cows - young stock 14 heifers and 16 calves - annual milk yield 7000 kg per cow containing 4.35% of fat and 3.4% of protein - herd calving interval 380 days - annual culling rate 30%

Gross return (per cow per year)				
milk (7000 kg x US$0.42)	US$	2940		
cattle inventory	-	440		
			US$	3380
Costs (per cow per year)				
labour (50 hrs x US$18)	US$	900		
machinery costs	-	460		
feed costs	-	672		
housing (depreciation, interest and maintenance)	-	540		
rent for land	-	203		
fertilizer	-	116		
health care	-	83		
others (artif.insem., electricity, interest, etc.)	-	500		
			US$	3474
Net profit (per cow per year)		-/-	US$	94
Net return to labour and management (per cow / year)			US$	806
Net return to labour and management (total herd / year)			US$	36270

Appendix 4.2 Typical results for commercial Dutch sow farms

Herd size 150 sows - weaning at 30 days - 2.22 litters per sow per year - 10.8 pigs born alive per litter - mortality rate 14% - 9.3 pigs raised per litter - 20.6 pigs raised per sow per year

Gross return (per sow per year)					
20.6 pigs x US$64		US$	1318		
sow inventory	-/-	-	20		
				US$	1298
Costs (per sow per year)					
feed: sow (incl.repl.gilts) 1157 kg at US$0.24, and piglets 20.6 x 30 kg at US$0.40		US$	525		
housing (depreciation, interest and maintenance)		-	314		
labour		-	306		
health care		-	45		
interest (herd and feed stock)		-	36		
cost of transportation piglets		-	29		
others (artif.insem., water, electricity, etc.)		-	105		
				US$	1360
Net profit (per sow per year)			-/-	US$	62
Net return to labour and management (per sow / year)				US$	244
Net return to labour and management (total herd / year)				US$	36600

Appendix 4.3 Typical results for commercial Dutch pig fattening farms

Herd size 1600 hogs - 2.61 deliveries per year - mortality rate 2.8% - 4058 hogs sold per year - starting weight 25 kg - ending weight 110 kg - daily weight gain 715 gr - net fattening period 119 days

Gross return (per hog sold)				
85.3 slaughter weight x US$2.09			US$	178
Costs (per hog sold)				
feed: feed conversion 2.88 and 85 kg of weight gain makes 245 kg of feed at US$0.28	US$	69		
purchase piglet	-	64		
housing (depreciation, interest and maintenance)	-	20		
labour	-	10		
interest (herd and feed stock)	-	3		
cost of transportation hogs	-	3		
health care	-	2		
others (water, electricity, mortality, etc.)	-	8		
			US$	179
Net profit (per hog sold)		-/-	US$	1
Net return to labour and management (per hog sold)			US$	9
Net return to labour and management (total herd / year)			US$	36522

5

Critical steps in systems simulation

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Objectives

From this chapter the reader should gain knowledge of:

- the critical steps to be taken in systems simulation (ie, definition of the system and statement of objectives, analysis of data relevant to the model, model construction, validation of the model, sensitivity analysis, and application of the model)
- how to make a better choice from modelling types and techniques, especially with respect to deterministic and stochastic models

5.1 Introduction

Models are essential tools for understanding animal health economics. Mathematical models are especially useful in this context and generally defined as a set of equations to describe or simulate an interrelated part (system) of the real world (Hillier & Lieberman, 1990). Three broad functions can be distinguished: (1) to provide an objective basis for assessing and assimilating available information about the system, (2) to detect where essential knowledge of the system is lacking or inadequate, indicating needs for further research, and (3) to assist in the management control of the system.

Basically, there are two different modelling approaches to be considered: a positive approach and a normative approach. The **positive approach** can best be indicated as a description of relevant processes and characteristics by statistical/epidemiological data analysis (the so-called empirical modelling). Traditionally, research in livestock production has mainly been conducted in this way. In animal health economics more attention is paid to the **normative approach**, which includes computer simulation techniques (the so-called mechanistic modelling). Computer simulation is a method for analysing a problem by creating a simplified mathematical model of the system under consideration which can then be manipulated by modification of inputs. This method is especially attractive where real-life experimentation would be impossible, costly or disruptive (eg, with highly contagious diseases), and for exploring strategies that have not been applied yet. Special attention has to be paid to the correspondence between model and reality to obtain meaningful results for real-world situations.

In this chapter the critical steps and basic concepts in systems simulation are presented and discussed.

5.2 Systems and systems analysis

The terminology associated with systems and systems analysis is generally a collection of terms that are used in other fields often with different meaning or connotation. In the model ling context, a system is generally described as a - complex - set of related components which exist within some pre-defined boundary and react as a whole to external or internal stimuli (eg, animal, herd, population). Placing of the boundary is considered the key issue

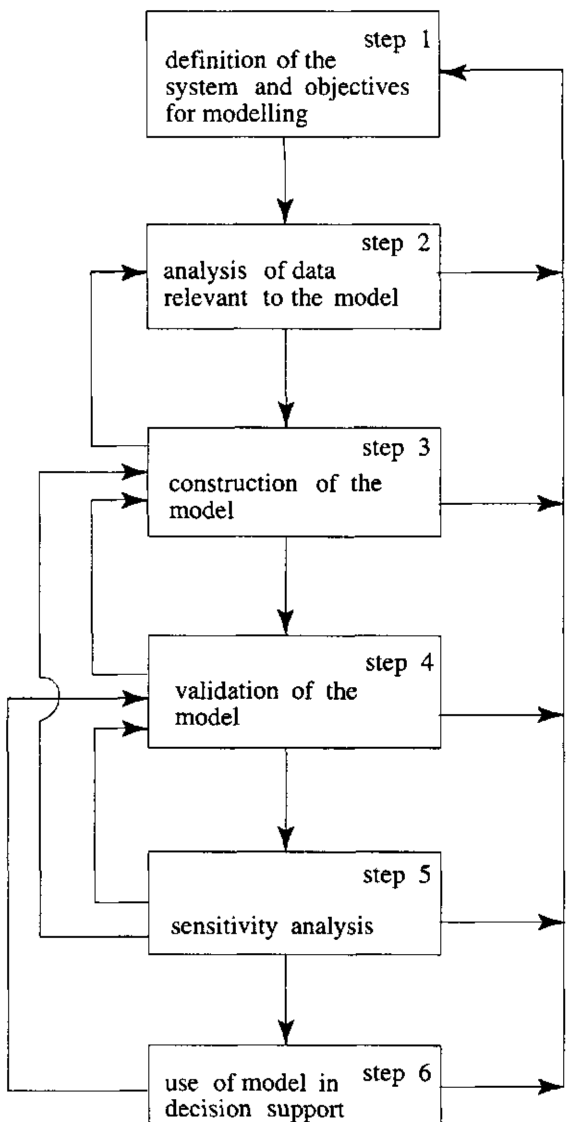

Figure 5.1 The basic steps of systems simulation

in defining and structuring any system, and should depend primarily on the function the model has to fulfil (Dent & Blackie, 1979).

The term systems analysis is generally used to refer to the process of examining complex systems, where all major inputs and outputs are accounted for by the use of mathematical models. Dent & Blackie (1979) consider six critical - and interlinked - steps involved in applying systems analysis, as presented in Figure 5.1. The steps are commented on one by one.

Step 1 Definition of the system and objectives for modelling

A clear description of the system and statement of the reasons why the system simulation work is being carried out is an essential first step. The system under consideration, the nature of the problems to be solved, the relevant data available, and to what degree of detail answers are required highly determine the type of model to be used. Different types of models are available to simulate a system (Law & Kelton, 1991). A first choice that should be made is that between **static** and **dynamic** models. A static model does not contain time as a variable and, therefore, cannot simulate the behaviour of a system over time, as opposed to a dynamic model. A model that makes definite predictions for quantities (such as milk production and live weight) is called **deterministic**. A **stochastic** model, on the other hand, contains probability distributions to deal with uncertainty in the behaviour of a system. These distributions can be used directly or through random sampling. In the latter case, repeated runs of the model are necessary to provide insight into the variation in outcome. A final difference to consider concerns **optimization** versus **simulation**. An optimization model determines the optimum solution given the objective function and restrictions, whereas a simulation model calculates the outcome of pre-defined sets of input variables (scenarios, strategies)

Step 2 Analysis of data relevant to the model

The model design is to a large extent dependent on the data available or on the feasibility of generating data within the time limits set by the research. Complete data availability will seldom, if ever, exist. An obvious shortage occurs when simulation studies are conducted in an early stage of research, eg, to explore new strategies that have not been applied yet. Especially then, however, simulation studies have proved to be beneficial to help structure the problem and set priorities for further (empirical) research. In those cases a close cooperation with experts may help to get the best estimates for the necessary input data and relationships. Once the model is available, the - potential - impact of uncertain estimates can easily be determined through sensitivity analyses (Step 5).

Step 3 Construction of the model

The construction of a mathematical model is usually a multistage procedure. Three functionally different approaches can be distinguished:

- the bottom-up approach, beginning with components of models at the lowest level of organization and combining them without any aggregation;

- the top-down approach, which begins with a simple representation of the entire system and is complete when the resolution of the model is sufficient to satisfy the objectives; and
- the prototyping approach, an iterative compromise between the first two alternatives.

Development of a model with the prototype approach begins with simple modelling of single subsystems. The process of development progresses by formulating more sophisticated representations of the most important subsystems and aggregating, deleting or ignoring subsystems of lesser importance. Because of its flexibility, the prototyping approach is especially favourable for models of large and complex systems, such as livestock production systems. It allows experts (as well as final users) to be included in the modelling process at an early stage. Regular interaction with these people maintains their interest in the simulation study. It can also help to avoid the mistake (often made by novice modellers) to start with too excessive an amount of model detail.

Step 4 Validation of the model

Validation is considered a very important but difficult step in the entire modelling procedure. The key issue here is to judge whether or not the model mimics reality sufficiently well to fulfil the purposes for which it has been developed. If a model is considered 'valid', then the decisions made with the model should be similar to those that would be made by physically experimenting with the system (if possible). If a model is not valid, then any conclusions derived from it will be of doubtful value.

In the literature a distinction is made between internal and external validation (Taylor, 1983). **Internal validation** is a continuous process throughout the development stage of the model, ensuring that all assumptions are in accordance with the theory, experience and relevant general knowledge. Internal validation can thus be described as ensuring that the right answer, decision or recommendation is provided by the correct method, and that each equation or part of the model has a logical basis, uses correct parameters and is correctly written. **External validation** refers to the comparison of the model's performance against the performance of the real system, in which the model is considered a 'black box'. Information should be produced, which enables the user to conclude whether to accept or reject the model's recommendation. This may include a sensitivity analysis (Step 5).

Two fundamental issues relate to the validation of any computer simulation model. First, the fact that a model behaving like reality for one set of inputs and operating rules does not guarantee that it will perform satisfactorily for a different set of conditions. Second, there is no totally objective and accepted approach to validation, because validation necessarily includes: (1) the way(s) in which the model is used, (2) the tests with which to validate the model, (3) the data to serve as a basis for comparison, and (4) the criteria to measure the (in)validity of the model. When a model and the results are accepted by the user as being 'valid', and are used as an aid in making decisions, then such a model is called 'credible' (Law & Kelton, 1991). Although credibility has not been discussed a great deal in literature on systems simulation, it is considered as important as validation in terms of actual implementation of simulation results.

Step 5 Sensitivity analysis

One of the most powerful decision-analytic techniques is **sensitivity analysis**, in which the values of relevant parameters are systematically varied over some range of interest to determine their impact on the results. If each of the assumptions is independent of all other assumptions, then it is reasonable to vary one parameter at a time, assuming all other parameters to be at their baseline or 'best guess' values. On the other hand, if several assumptions are interdependent, or if it seems important to examine the trade-off between specific gains and losses, then it is best to examine several parameters simultaneously.

Good knowledge of sensitive parameters should be available and entered into the model. If this is not available, sensitivity analysis can help to set priorities for further (empirical) research. In this way a valuable interaction between computer simulation and field data analysis is possible. Computer simulation may be used to quantify the significant gaps in (veterinary) knowledge, while knowledge obtained from field data research increases the realness of economic models. This interaction is considered fundamental to the study of disease and disease control.

Step 6 Use of model in decision support

If accepted, the model can be used for providing answers to the questions for which it has been built. This can be done either within a research environment only (ie, providing output for scientific publications) or as an actual tool for decision-support in the field. The latter use is on the increase. A so-called **Integrated Decision Support System** (IDSS) is commonly considered to be an ideal framework for model use under field conditions, and defined as a user-machine system for providing information to support operations, management and decision-making functions in an organization. The system utilizes computer hardware and software, manual procedures, models for analysis, planning, control and decision making, and a database (Davis & Olson, 1985). Marsh (1986), Huirne (1990), Jalvingh (1993) and Houben (1995) developed comprehensive but flexible models for on-farm decision support in the area of animal health and replacement economics in dairy cattle and swine, meant to be included in the model base of such an IDSS.

Different ways can be considered to actually make these models available for use in the field. As a start, the models could be made available for a central computer, which can be accessed by individual users (farmers, advisers). In case of indirect use, the adviser carries out the model calculations and interprets and reports the results to the farmer (intermediary mode). In case of direct use, the farmer and the adviser may use the model on-line (terminal mode), or off-line (clerk mode) by preparing and submitting input to the central computer. The final step is to have the models available on the PC of both the adviser and the farmer.

5.3 Deterministic and stochastic modelling

In the previous section a deterministic model was described as being a model that makes definite predictions for quantities (such as milk production and live weight), whereas a stochastic model contains either probability distributions or random elements to deal with uncertainty in the behaviour of a system. In the literature there is agreement on the distinction between (pure) deterministic models on the one hand and stochastic models containing random elements on the other. This is not the case with respect to stochastic models containing probability distributions. Several authors classify these models as being deterministic, which is not correct and may underestimate their value and potential applications. Therefore, the three different types of models will further be illustrated and discussed, by using a simplified example.

Consider the situation where for a model dealing with sow replacement economics, a young replacement sow is taken from a population where the size of the first litter is normally distributed (see Figure 5.2). Litter size in this example ranges from 6 to 12 pigs and most sows (ie, 30%) fall into the class with 9 pigs per litter. The expected performance of a replacement sow taken from this population depends upon the type of model under consider ation. In case of a **deterministic model**, each replacement sow is considered to produce exactly 9 pigs in her first litter, this being the most likely litter size of the population she comes from. All costs and returns in the calculation then are also derived from such a 9-pig sow. In a **stochastic model with probability distributions**, each replacement sow is expected to produce 0.05 x 6 + 0.10 x 7 + ... + 0.10 x 11 + 0.05 x 12 = 9.0 pigs in the first litter. Now the costs and returns in the calculation are derived (ie, weighed) from the various single litter-size classes under consideration. This is a fundamentally different approach from the deterministic model and will lead to different economic results as well. In case of a **stochastic model with random elements**, each replacement sow is randomly drawn from the specified probability distribution and will have a litter size of 6, 7, ..., or 12 pigs. The costs and returns, therefore, will differ accordingly between the sows. With a sufficiently

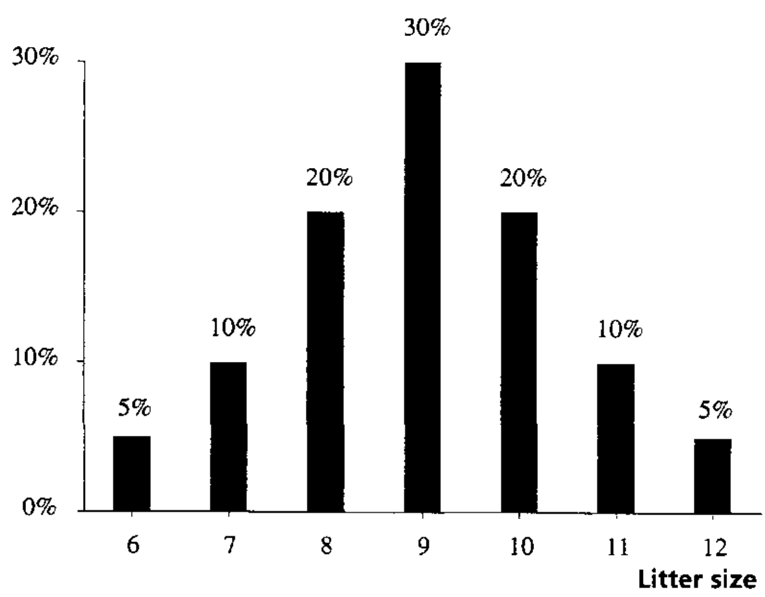

Figure 5.2 First-litter size performance in a sow population

large number of drawings (ie, multiple runs) the average litter size of the replacement sows will approximate 9.0 pigs again, providing the same average economic outcome as the stochastic model using probability distributions.

As illustrated in the example, deterministic models do not take into account uncertainty (ie, variation) associated with future events, resulting in an oversimplification of the conditions under which decisions have to be made in reality. The approach using probability distributions (ie, dynamic probabilistic or (modified) Markov chain simulation) and the one using random numbers (ie, Monte Carlo simulation) have the advantage that, for instance, animals with different performances can be treated differently, eg, a more liberal insemination and replacement policy for high-producing animals. Moreover, future performance can be related to current performance. Therefore, culling of animals with a low performance will influence the performance realized in later production cycles. In the deterministic approach this is not possible; the resulting average performance per production cycle is always equal to the input value.

One advantage of the approach using probability distributions is that there will be observations in all classes, which means that the model will exactly provide the expected value of the results and only **one run** is needed to obtain these results. In fact, the results of a very large herd or population are simulated, with animals available in all possible states. In the model using random numbers, the presence of observations in all classes is not guaranteed. The larger the number of observations, the better the average result will approach the real expected value. Replicated calculations are needed to obtain a reliable estimate of the average results.

One advantage of models with random numbers and multiple runs, on the other hand, is the available information about the expected **standard deviation** in the results, which allows for statistical tests and non-neutral risk analysis. Performing these tests and analyses requires a careful design and analysis of the modelling experiments, in order to obtain reliable estimates of average results and standard deviations. By simply choosing a large number of replications, for instance, a difference between two strategies can always be made significant, due to the fact that the standard error of the mean will then be small.

Applications of stochastic models with random elements often focus on the comparison of average results only, rather than on a trade-off between expected outcome and its variation (ie, non-neutral risk analysis). If so, then the approach using probability distributions had better be applied. Since one run supplies the expected value of the results, various sensitivity analyses can be carried out much easier than is the case with models using random numbers.

An overview of published models and their features in the area of reproduction and replacement economics in dairy cattle and sows was given by Jalvingh (1993).

5.4 Common combinations of modelling type and technique

The choice of the modelling type and technique will depend on a number of factors, including:

- the nature of the problem;
- the resources available, eg, time, money and analytical tools; and

- the availability of data and information about the problem.

Even within specific narrow problem domains such as animal replacement decisions, diffe rent modelling types and techniques are used. Most common combinations in the literature are summarized in Table 5.1.
Model calculations in animal health economics often suffer from a serious lack of accurate data, as discussed before. Since the mid-eighties much effort has been put into designing and implementing integrated veterinary, zootechnical and economic record keeping systems (Morris & Dijkhuizen, 1992). In the future, systematic epidemiological and economic analyses of these databases should be given high priority. A basic question is whether - and, if so, which - standards are available to express the frequency and severity 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.

Table 5.1 Common combinations of modelling type and technique[a]

				Stochastic			
	Static	Dyna-mic	Determi-nistic	Probab. distrib.	Random elements	Optimization	Simulation
Gross Margin Analysis	x		x				x
Partial Budgeting	x		x				x
Cost-Benefit Analysis		x	x				
Decision Analysis	x			x			x
Linear Programming	x		x			x	
Dynamic Programming		x		x		x	
Markov Chain Simulation		x		x			x
Monte Carlo Simulation		x			x		x

[a] The first four (basic) methods of economic analysis in this table were explained in Chapter 3; the other, more advanced ones, will follow in the next chapters.

References

Davis, G.B. & Olson, M.H., 1985. Management information systems. Conceptual foundations, structure and development. McGraw-Hill, New York, 693 pp.

Dent, J.B. & Blackie, M.J., 1979. Systems simulation in agriculture. Applied Science Publisher Ltd., London, 180 pp.

Hillier, F.S. & Lieberman, G.J., 1990. Introduction to operations research. McGraw-Hill, New York, 954 pp.

Houben, E.H.P., 1995. Economic optimization of decisions with respect to dairy cow health management. PhD-Thesis, Department of Farm Management, Wageningen Agricultural University, Wageningen, 146 pp.

Huirne, R.B.M., 1990. Computerized management support for swine breeding farms. PhD-Thesis, Department of Farm Management, Wageningen Agricultural University, Wageningen, 165 pp.

Jalvingh, A.W., 1993. Dynamic livestock modelling for on-farm decision support. PhD-Thesis, Department of Farm Management and Department of Animal Breeding, Wageningen Agricultural University, Wageningen, 164 pp.

Law, A.M. & Kelton, W.D., 1991. Simulation modeling and analysis. McGraw-Hill, New York, 759 pp.

Marsh, W.E., 1986. Economic decision making on health and management in livestock herds: examining complex problems through computer simulation. PhD-Thesis, University of Minnesota, St. Paul, 304 pp.

Morris, R.S. & Dijkhuizen, A.A., 1992. The application of computer software in the management of fertility disorders in pigs. Proceedings 12th Congress of the International Pig Veterinary Society, Amsterdam, I: 45-48.

Taylor, A.J., 1983. The verification of dynamic simulation models. Journal of Operational Research Society 34: 233-242.

6

Linear programming to meet management targets and restrictions

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Objectives

From this chapter the reader should gain knowledge of:

- the characteristics of linear programming
- the formulation of a linear programming model
- the solving procedure
- the assumptions used

The method is introduced by a simplified example and further illustrated with an application to optimizing a dairy herd calving pattern.

6.1 Introduction

Being managers, farmers need to allocate limited resources to competing activities in the best possible way. The allocation problem can be solved by analysing a large number of alternatives, using techniques such as partial and whole-farm budgeting. With the budgeting procedure, however, each single plan has to be identified and evaluated by detailed calculations. For complex problems, such calculations are time-consuming and become tedious and burdensome. Moreover, it is only by chance that the plans chosen for budgeting analysis include the optimal one.

Linear programming uses the same type of information as is done in the budgeting procedure, but the mathematical technique involved guarantees that the optimal plan is determined. The essential **characteristics** of a linear programming model are that (1) there is a function to be maximized or minimized, (2) there are limited resources that can be used to satisfy the objective, and (3) there are several ways of using the resources (Heady & Chandler, 1958). In agriculture, linear programming is most extensively used in determining least-cost rations and in planning the farm business organization (Boehlje & Eidman, 1984). In determining the least-cost ration, the objective can be to minimize the cost of meeting the nutritional requirements of a certain type of livestock while using particular feed ingredients. In planning the farm business, land, labour and machinery and equipment resources are allocated to competing activities such as production of different crops and different types of livestock production in order to maximize income.

The method of linear programming is first introduced and illustrated with an example.

Assume that at the start of the grazing season, all beef cattle on a farm are treated with an anthelmintic. For years the farmer has used anthelmintic A. Recently, anthelmintic B has come on the market. Anthelmintic A costs US$2 per animal and B US$6. The firms that produce the anthelmintics have carried out experiments to estimate the effect of applying the anthelmintics. According to these experiments, A leads to an increase in live weight of 20 kg, while B leads to an increase of 40 kg, if compared with animals that have not been treated. Although the veterinarian is enthusiastic about anthelmintic B, the farmer is a bit reluctant to use it because of the higher costs. The farmer decides that (s)he wants to maximize the total effect of the therapy, but does not want to spend more than US$600 on anthelmintics. Furthermore, the number of animals to be treated should not exceed 150.

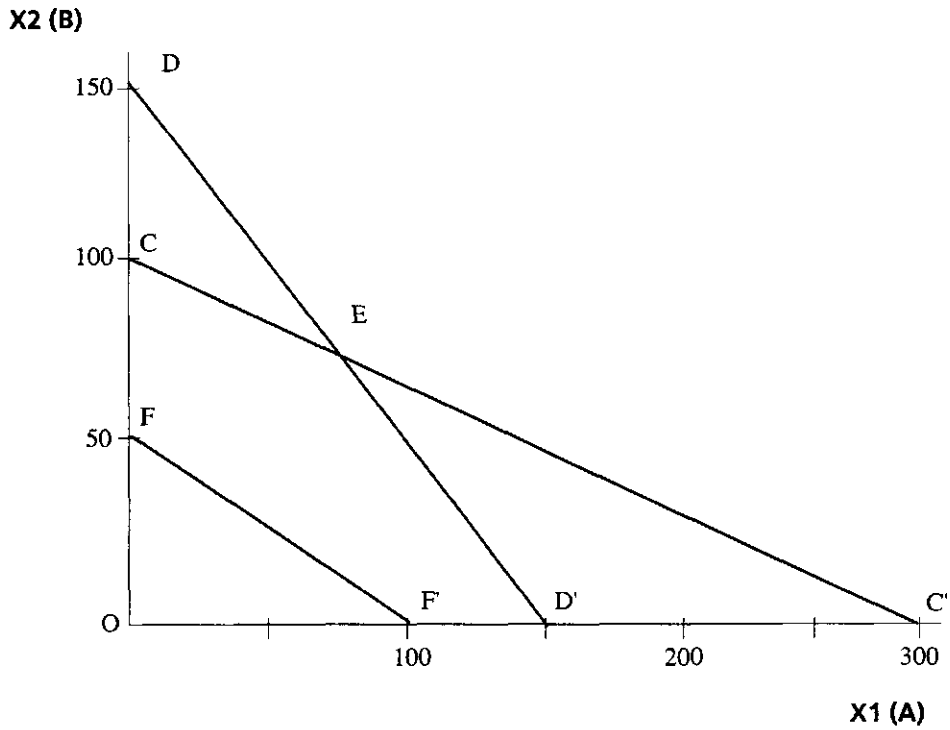
This problem can be formulated as a linear programming problem. It refers to a situation of allocating limited resources (money, number of treatments) to competing activities (treat ment with anthelmintics A and B) in order to maximize a certain objective (the total effect of the treatment). To formulate the mathematical model of the problem, let x_1 and x_2 represent the number of treatments with A and B respectively. Let Z be the resulting effect on extra live weight gain for the herd as a whole; x_1 and x_2 are the decision variables (activities) for the model. The relationship between Z and x_1 and x_2 is as follows: $Z = 20x_1 + 40x_2$. The objective is to choose the values of x_1 and x_2 so as to maximize Z, subject to the restrictions on their values imposed by the farmer. Thus the mathematical formulation of the problem is as follows:

$$\text{Maximize } Z = 20x_1 + 40x_2$$

subject to the restrictions

$$\begin{aligned} 2x_1 + 6x_2 &\leq 600 \\ x_1 + x_2 &\leq 150 \\ x_1 \geq 0, x_2 &\geq 0 \end{aligned}$$

It is necessary to define the decision variables to be nonnegative. This small problem has only two decision variables, and therefore only two dimensions, and hence a graphical procedure can be used to solve it. This procedure involves constructing a two-dimensional graph with x_1 and x_2 as the axes. The first step is to identify the values of x_1 and x_2 that are permitted given the restrictions. This is done by drawing the lines that border the range of permissible values. The graphical representation of the linear programming problem is given in Figure 6.1. First, each restriction is treated separately. Resulting from the restriction on the amount of money to be spent on the treatments (ie, US$600), 300 animals can be treated with A, 100 animals with B, or any linear combination of A and B. This is depicted in Figure 6.1 as line CC'. The constraint on the total number of animals to be treated results in 150 animals treated with A, 150 animals treated with B or any linear combination of A and B (line DD'). If all constraints are considered simultaneously, any points inside the area or at the boundary of OCED' are feasible combinations of treatments with A and B. This area is known as the **'feasible set'**.



The final step is to identify the point in this region that maximizes the value of Z. The optimal combination of the number of treatments A and B depends on their relative efficiency. Two animals treated with A will have the same total weight gain as one animal treated with B. The line FF' in Figure 6.1 denotes those combinations of x_1 and x_2 that generate a total effect of 2000 kg. With line FF' moving to the right, higher levels of total weight gain are obtained. In case of minimization the line FF' has to be moved into the direction of lower levels of Z. The line is moved to the right until it touches the farmost edge of the feasible set point E). Combinations of numbers of treatments are not possible beyond this point because adequate quantities of the money and/or animal resources are not available. If we draw a line from point E to each axis of the graph, they indicate that 75 treatments with A and 75 treatments with B will maximize the effect of the total treatment (Z = 75 x 20 + 75 x 40 = 4500 kg). When more constraints and decision variables are added, the example becomes a multidimensional problem that will be impossible to represent graphically. The underlying principle of the optimization procedure of linear programming, as illustrated in this simplified example, remains the same, however.

6.2 Linear programming models in general

6.2.1 General formulation

With the above-mentioned simplified example in mind, we will now give the general formulation of the linear programming model. A linear programming model has the objective to select the values for $x_1, x_2, ..., x_n$ (the decision variables or activities) so as to

$$\text{Maximize or Minimize } Z = c_1x_1 + c_2x_2 + ... + c_nx_n$$

subject to the restrictions

$$\begin{array}{l} a_{11}x_1 + a_{12}x_2 + ... + a_{1n}x_n \leq b_1 \\ a_{21}x_1 + a_{22}x_2 + ... + a_{2n}x_n \leq b_2 \\ \quad . \qquad . \qquad . \\ \quad . \qquad . \qquad . \\ a_{m1}x_1 + a_{m2}x_2 + ... + a_{mn}x_n \leq b_m \\ \text{and } x_1 \geq 0, x_2 \geq 0, ..., x_n \geq 0 \end{array}$$

The function being maximized or minimized, $c_1x_1 + c_2x_2 + ... + c_nx_n$, is called the **objective function**, with x_j being the decision variables. The restrictions are normally referred to as **constraints**. The first m constraints, representing the total usage of resource b_i, are called functional constraints. Similarly, the $x_j \geq 0$ restrictions are called nonnegative constraints. The model may also include 'greater than or equal to' constraints, as well as equality constraints. The input constants, a_{ij}, b_i and c_j, are referred to as parameters of the model.

The basic structure of any linear programming model is a matrix, with the columns in that matrix being the processes or activities and the rows the resource constraints. Three general types of constraints are usually included:

- real constraints which limit physical resource availability;
- institutional and subjective constraints which reflect limits imposed by the outside institutions or personal preferences of the operator; and
- accounting constraints which are used to keep track of resources or will provide structure to the model.

A linear programming problem has different types of solutions. The **feasible solution** is a solution for which all constraints are satisfied. The feasible region is the collection of all feasible solutions. It is possible that there is no feasible solution to a problem. This would be the case if in the linear programming example from the previous section at least 110 animals were treated with anthelmintic B. If there are feasible solutions, linear programming should find which one is best, measured against the value of the objective function of the model. An **optimal solution** is a feasible solution that results in the most favourable value of the objective function. So, the optimal solution maximizes or minimizes the objective function over the entire feasible region. Most problems will have just one optimal solution. It is possible, however, to have more than one. This would be so in the example above if the effectiveness of treatment B was modified such that all points on line segment EC' in Figure 6.1 would be optimal.

6.2.2 Solving procedure

For the sake of convenience, a precise set of mechanical rules has been developed to solve a linear programming model. These rules specify each step that is to be taken during the solution process, and are actually a trial-and-error procedure for problem solving. However, they have been constructed in such a way that each trial results in an improved answer. The rules also guarantee that, if an optimal value exists, it will be found within a finite number of steps (Heady & Chandler, 1958).

The mechanical rules for solving linear programming problems are collectively known as the **simplex method**. The previously discussed characteristics of a linear programming model and the example presented will be used to provide a basic understanding of the simplex procedure[1].

It was shown earlier that the optimal combination of treatments with A and B occurred at the boundary of the feasible set at the point of intersection between the constraints with respect to the maximum amount of money to be spent and the maximum number of animals to be treated. This intersection is referred to as a 'corner point'. It can be proven mathematically that the optimal solution will always be at a corner point. Thus, to determine the optimum, the only points that need to be investigated during the trial-and-error process of the simplex method are the corner points at the boundary of the feasible set. This is exactly how the mechanical rules of the simplex procedure operate: they search the corner points of the boundary of the feasible set in a sequential fashion. For example, the procedure starts at the original corner point of Figure 6.1 and moves along the axis of treatment with A to the corner point denoted by D'. Profit is evaluated at that point and then the next corner point of the feasible space, corner point E, is investigated. Once corner point E has been evaluated, the simplex method investigates the possibility of moving to corner point C. Since corner point C has a lower objective function value than corner point E, the procedure will stop and declare corner point E the optimum. The mechanical rules of the simplex method are structured such that each following corner point should result in a higher value of the objective function. Once a corner point that has a lower value is reached, further investigation is unnecessary because no other corner point in the feasible set has a higher value of the objective function, so an optimal solution has been found.

Information on the economic contribution of the various resources to the measure of performance (Z) is extremely useful. The simplex method provides this information in the form of **shadow prices** for the respective resources.

[1] No time will be devoted to discussing this method in detail. Those who are interested may consult numerous works which provide detailed discussions on this procedure along with examples that can be solved by hand (see, for example, Heady & Chandler, 1958; Boehlje & Eidman, 1984; Dent *et al.*, 1986; Hillier & Lieberman, 1990).

The shadow price for resource i (denoted by y_i) measures the marginal value of this resource, that is, the rate at which Z would be increased by (slightly) increasing the amount of this resource (b_i).
The shadow prices for the anthelmintic problem are calculated as follows:

$y_1 = 5$ is shadow price for resource 1
$y_2 = 10$ is shadow price for resource 2

where these resources represent the maximum amount of money the farmer wants to spend on anthelmintics and the maximum number of animals to be treated. These numbers can be verified by checking in Figure 6.1 that individually increasing each b_i by 1 would indeed increase the optimal value of Z by 5 and 10 respectively. For example, the optimal solution, (75, 75) with Z = 4500, changes to (76½, 74½) with Z = 4510 when b_2 is increased by 1 (from 150 to 151), so that

$$y_2 = \Delta Z = 4510 - 4500 = 10$$

The kind of information provided by shadow prices is especially valuable to the management when it considers reallocations of resources within the organization. It is also helpful when an increase in b_i can be achieved only by purchasing more of the resource. For example, suppose that Z represents profit and the unit profits of the activities include the costs of all the resources consumed. Then a positive shadow price of y_i for resource i means that the total profit Z can be increased by y_i by purchasing one more unit of this resource at its regular price. Alternatively, if a premium price has to be paid for the resource, then y_i represents the maximum premium that will be worth paying. So, based on the shadow prices of a certain resource, it may be decided to increase its amount.
Sensitivity analysis can be used to identify the most sensitive parameters. One parameter at a time is changed and its influence on the optimal solution determined. Typically, more attention is given to performing sensitivity analysis on the b_i and c_j parameters than to that on the a_{ij} parameters. In many cases, a_{ij} values are determined by the technology being used, so there may be relatively little (or no) uncertainty about their final values. Parametric programming involves the systematic study of how the optimal solution changes if many of the parameters change simultaneously over some range. This technique can be used to study the effects of trade-offs in parameter values.
Because of their mechanical nature, the rules representing the simplex method have been computerized so that only the model of the problem needs to be developed and submitted to the computer for 'number-crunching' (optimal solution and sensitivity analysis). Various software packages that can carry out these tasks on mainframe and personal computers are available. Some examples are XA (Sunset Software Technology, San Marino, Ca, USA), LINDO (The Scientific Press, Palo Alto, Ca., USA), MICRO-LP (Scicon Ltd, Milton Keynes, UK) and OMP (Beyers & Partners nv, Brasschaat, Belgium).

6.3 Assumptions of linear programming

Several assumptions are used in linear programming. Four basic assumptions are essential to determine whether linear programming is applicable to a particular problem and whether it will provide a meaningful and precise answer (Heady & Chandler, 1958; Boehlje & Eidman, 1984; Hillier & Lieberman, 1990).

Additivity and linearity in input and output coefficients

The additivity assumption specifies that the total amount of resources used for two or more activities must be the sum of the amounts of resources used for each separate activity. The same assumption applies to products produced. The implication of this is that interaction between activities is not allowed. If necessary, this can be included by adding a new process that reflects the complementarity between two activities (eg, crop rotation).

The assumption of linearity follows directly from that of additivity. Linearity implies that multiplying all inputs used in an activity by a constant results in a constant change in the output of that process. Thus, the production function for an activity is linear. To reflect nonlinear production relationships, these relationships are approximated by linear segments, with each linear segment representing a separate activity or decision variable. The assumptions of linearity and additivity refer to relationships between activities.

Divisibility in resources and products

The divisibility assumption is that activity units can be divided into any fractional level, so that noninteger values for the decision variables are permissible. Frequently linear programming is applied, even if an integer solution is required. If the solution obtained is a noninteger one, then the noninteger variables are merely rounded to integer values. However, the optimal linear programming problem is not necessarily feasible after the variables have been rounded. Even if it is feasible, there is no guarantee that this rounded solution will be the optimal integer one. Because the mathematical procedure requires complete divisibility of inputs and outputs, a practical interpretation of the results requires the judgment of the user.

Finiteness

This assumption sets a limit to the number of alternative processes and resource restrictions that can be included in the analysis. In fact, this number will depend on the software package used to solve the linear programming problem. Most packages will allow thousands of activities and restrictions.

Single-valued expectations

The single-valued expectations assumption essentially eliminates the important dimension of risk from linear programming analysis. This assumption specifies that resource supplies, input-output coefficients, and commodity and input prices must be known with certainty. Although many will argue that this assumption is unrealistic and makes the results suspect, it should not lead to rejecting linear programming altogether. First, the same assumption is required in many other analysis procedures used in animal health economics, including partial budgeting and gross margin analysis. Second, prices and production coefficients can easily be varied in the linear programming framework, and this 'sensitivity analysis' can illustrate the resource allocation and income impacts of alternative sets of prices and production efficiencies.

The assumptions in perspective

A mathematical model is intended to be only an idealized representation of reality. Approximations and simplifying assumptions generally are required in order to keep the model tractable. It is very common in real applications that almost none of the four assumptions hold completely. If the assumptions of linear programming are considered too restrictive, techniques are available to relax them. Nonlinear, separable and quadratic programming techniques can be used to handle nonlinear functions. Integer programming can be used in situations where fractional amounts of inputs or outputs are not feasible from a technical nor from a practical point of view. Stochastic and quadratic programming procedures can be used to incorporate risk dimensions in the analysis, replacing the single-valued expectations requirement. Applying these techniques results in increased complexity of model construction, reduced model size and higher costs of solving the model.

Exercise

In Chapter 19 you can find a computer exercise similar to the example given in the introduction of this chapter. You will practise the principles of linear programming by allocating the limited resources labour and grass to the competing activities sheep and cows in order to maximize the net returns. You have to define the restrictions to get a graphical representation of this problem. With the objective function you can find the optimal solution. Some sensitivity analyses can be carried out to see the effect of changes in net returns. The whole exercise takes approximately 40 minutes.

6.4 A more realistic application to herd calving pattern

6.4.1 Outline of the linear programming model

Jalvingh (1993) developed a dynamic probabilistic simulation model for dairy herds. The model simulates the technical and economic consequences of decisions concerning production, reproduction, replacement and calving pattern and can be tailored to individual farm conditions. The user has, for instance, the possibility of comparing different calving patterns and studying the effects on gross margin and labour. From this comparison the user has to choose the calving pattern that suits the objectives best. This is not necessarily the optimal calving pattern for that specific farm. The optimal calving pattern of a herd can be derived by combining the results of the simulation model with linear programming. The basic ingredients of the linear programming are the technical and economic results of the twelve so-called **single-month equilibrium herds** (SME-herds). An SME-herd represents a herd in which all heifers calve in the same month. The resulting herd dynamics are based on biological variables on the one hand (eg, conception rate and oestrus detection rate) and management strategies on the other (eg, insemination and replacement policy). Input variables of performance and prices are combined with the information on herd dynamics to obtain the technical and economic results of each SME-herd. The technical and economic results of any herd can easily be obtained by weighing the results of the twelve SME-herds according to the proportion of heifer calvings per month. The technical and economic results of the twelve SME-herds and the weighing of the SME-herds form the basic ingredients of the linear programming problem. The major results of the SME-herds are given in Table 6.1. The major input variables used to determine the results of the SME-herds are in Appendix 6.1.

The linear programming problem uses the number of heifers calving per month as decision variables. The objective is to choose the number of heifer calvings per month so as to maximize gross margin of the resulting herd, with the restriction that the annual milk production of the herd should not exceed the available milk quota. The following linear programming problem can be formulated:

$$\text{Maximize } Z = \sum_{i=1}^{12} gm_i x_i$$

subject to

$$\sum_{i=1}^{12} mp_i x_i \leq \text{quota}$$

where

x_i = number of heifers calving in month i;

gm_i = gross margin of the SME-herd expressed per heifer calving, in case the heifer calves in month i (see Table 6.1); and

mp_i = milk production of the SME-herd expressed per heifer calving, in case the heifer calves in month i (see Table 6.1).

As can be seen, the coefficients of the objective function and the constraint are derived from the results of the SME-herds. For that reason, the results of the SME-herds are expressed per calving heifer (Table 6.1).

The optimal solution of the linear programming problem represents the optimal **heifer** calving pattern. The optimal **herd** calving pattern and the corresponding technical and economic results can be derived by weighing the results of the SME-herds according to the optimal heifer calving pattern.

The linear programming problem just presented is referred to as **set I**. This set can be extended by adding other constraints. The optimal herd calving pattern was also determined for two different sets of additional constraints.

Table 6.1 Results of SME-herds

	Single-month equilibrium herd											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Annual culling rate(%)	37.4	40.1	40.8	38.9	35.8	34.3	33.0	31.7	31.6	30.0	31.7	33.9
Calving interval (days)	370	370	371	372	372	372	372	373	372	371	370	370
Per calving heifer												
Number of cows	2.67	2.49	2.45	2.57	2.79	2.92	3.03	3.16	3.17	3.34	3.16	2.95
Number of calvings	3.12	2.95	2.94	3.07	3.30	3.44	3.55	3.67	3.67	3.78	3.59	3.38
Milk production (kg)	19266	17825	17339	17969	19375	20110	20803	21750	22113	23740	22747	21336
Gross margin (US$)	6364	5844	5702	6021	6626	6964	7266	7605	7705	8246	7783	7178
Per average cow												
Milk production (kg)	7214	7150	7069	6997	6940	6893	6861	6891	6978	7116	7209	7242
Gross margin (US$)	2383	2344	2325	2344	2374	2387	2396	2409	2431	2472	2467	2436
Per 100 kg of milk												
Average monthly deviation in base price (US$)	0.38	-0.63	-0.66	-0.49	-0.22	0.12	0.47	0.73	0.87	0.80	0.47	0.02
Gross margin (US$)	33.03	32.79	32.89	33.51	34.20	34.63	34.92	34.97	34.84	34.73	34.22	33.62

In **set II**, an additional restriction is used, which specifies that all replacement heifers entering the herd should come from heifer calves that were born in the herd 24 months before. This can be formulated in twelve constraints:

$$\sum_{i=1}^{12} f_j x_{ij} x_i \geq x_j, \text{ for all } j$$

where

y_{ij} = number of herd calvings in month j in SME-herd corresponding to one heifer calving in month i; and

f_j = factor representing the number of 24-month-old replacement heifers per calving in month j that becomes available in month j 2 years later (f_j is set at 0.4 for all months).

All replacement heifers are assumed to calve at the age of 24 months, but this age at first calving can easily be changed to include variation.

A concentration of calvings within a few months results in a large variation in the monthly herd size. In **set III**, variation in monthly herd size is restricted by using a lower and upper limit between which monthly herd size is allowed to vary. The limits are formulated in terms of a proportion of the average annual herd size. In formula:

$$\sum_{i=1}^{12} hs_{ij} x_i \geq \sum_{i=1}^{12} \min\ ahs_i x_i, \text{ for all } j$$

$$\sum_{i=1}^{12} hs_{ij} x_i \leq \sum_{i=1}^{12} \max\ ahs_i x_i, \text{ for all } j$$

where

hs_{ij} = herd size of SME-herd in month j, in case one heifer calves in month i;

ahs_i = average annual herd size in SME-herd, in case one heifer calves in month i (see Table 6.1);

min = lower limit of the variation in herd size per month, expressed as a proportion of the average annual herd size; and

max = upper limit of the variation in herd size per month.

The lower and upper limits for variation in monthly herd sizes are set at 95 and 105% of the annual average herd size respectively. The constraints used in set II also hold for set III.

6.4.2 Results

The optimal heifer and herd calving patterns for the different sets of constraints are presented in Table 6.2, together with the technical and economic results of the herds.

Table 6.2 Results of the optimum herd calving pattern for different sets of constraints

	Set of constraints		
	I	II	III
Milk production herd (kg)	500000	500000	500000
Calving pattern heifers (%)			
January	0.0	0 0	0 0
February	0.0	0.0	0.0
March	0.0	0.0	0.0
April	0.0	0 0	0 0
May	0.0	0 0	0 0
June	0.0	0.0	13.7
July	0.0	23.9	21.8
August	100.0	32.4	23.7
September	0.0	37.2	10.2
October	0.0	6.5	19.6
November	0.0	0.0	9.6
December	0.0	0.0	0.0
Calving pattern herd (%)			
January	1.6	2.1	2.6
February	0.9	1.1	1.5
March	0.5	0.6	1.0
April	0.6	0.8	1.6
May	1.8	2.1	4.3
June	4.9	5.5	10.6
July	13.1	16.4	15.0
August	43.2	22.2	16.4
September	14.5	25.5	15.5
October	10.2	13.2	16.8
November	5.6	6.6	10.1
December	3.1	3.9	4.6
Average number of cows	72.6	72.1	71.7
Range herd size (% of average)	87-117	90-113	95-105
Number of calvings	84.3	83.7	83.0
Annual culling rate(%)	31.7	31.8	32.0
Calving interval (days)	373	372	372
Milk per average cow (kg)	6891	6932	6972
Average monthly deviation in base price milk (US$/100 kg)	0.73	0.73	0.59
Economic results (US$/100 kg of milk)			
Revenues - milk	46.91	46.87	46.66
- calves	3.41	3.33	3.31
- cullings	3.85	3.86	3.88
Costs - feed	12.45	12.43	12.36
- heifers	6.74	6.72	6.70
Gross margin	34.98	34.91	34.78
Gross margin herd (US$)	174913	174551	173922

As expected, the highest gross margin per 100 kg of milk is realized when only the milk production of the herd is restricted (set I). In that case, all heifer calvings take place in August, which could be expected from the information presented in Table 6.1. The resulting herd calvings, including heifer calvings, take place mainly from July to October. The proportional monthly milk production varies from 4.3% in June to 11.3% in September. The variation in monthly milk production is much smaller than the variation in monthly herd calvings. The monthly herd size, expressed as a percentage of the average annual herd size, varies from 87% in July to 117% in August.

If the number of heifers calving per month is restricted by the number of heifer calves born in the herd in each month (set II), heifer calvings occur from August to October. The resulting herd calvings are still concentrated in the period from August to October. The gross margin is reduced by only US$0.07 per 100 kg of milk, which is US$362 at herd level. The reduction in gross margin is a result of the reduction in milk and calf revenues. The milk revenues are reduced because of the reduction in average-realized monthly deviation in the base price of milk, whereas the revenues from calves are reduced because of the reduction in the number of calvings in the herd. In set II, the monthly herd size varies from 90% in June to 113% in September of the average annual herd size (Table 6.2).

In set III, the monthly herd size is restricted to vary between 95 and 105% of the average annual herd size, resulting in an optimal heifer calving pattern that is spread over a longer period than in set II. The gross margin is reduced by US$0.20 per 100 kg of milk compared with set I, which equals US$991 at herd level.

The optimal herd calving pattern can also be determined for herds with a lower reproductive performance, or different prices, performance etc. Only a few constraints have been demonstrated in this chapter. However, it is possible to include other constraints, such as restrictions on roughage supply or available labour, as well. The objective function of the problem can also be modified. Gross margin of the herd can be maximized while herd size rather than the annual milk production is restricted (ie, for a situation without a milk quota system).

6.5 Concluding remarks

Linear programming is a very useful tool in finding the optimal solution for complex problems. The technique has not much been applied yet in animal health economics. The reason for that might be unfamiliarity with the technique or that it is not considered useful. Linear programming has several clear underlying assumptions (limitations). Many modifications have been made to the technique to deal with these limitations, such as mixed-integer, nonlinear and quadratic programming. As a result of the advances in computer technology (higher speed and larger memory capacities), computing facilities are now easily available for everybody. Furthermore, recently developed interactive menu-driven packages may greatly facilitate the application of these techniques.

References

Boehlje, M.D. & Eidman, V.R., 1984. Farm management. John Wiley & Sons, New York, 806 pp.

Dent, J.B., Harrison, S.R. & Woodford, K.B., 1986. Farm planning with linear programming: concept and practice. Butterworths, Sydney, 209 pp.

Heady, E.O. & Chandler, W., 1958. Linear programming methods. The Iowa State University Press, Ames, 597 pp.

Hillier, F.S. & Lieberman, G.J., 1990. Introduction to operations research. McGraw-Hill, New York, 954 pp.

Jalvingh, A.W., 1993. Dynamic livestock modelling for on-farm decision support. PhD-Thesis, Department of Farm Management and Department of Animal Breeding, Wageningen Agricultural University, Wageningen, 164 pp.

Appendix 6.1

See Jalvingh (1993) for more details on input variables and for a complete overview. The given input values are assumed to represent typical Dutch herds, but they can easily be modified to suit other farm and price conditions.

Herd dynamics model

Proportions of first inseminations for months 2 to 5 after calving are 44, 41, 11 and 4% respectively. After second calving and later these proportions are 49, 38, 10 and 3%. Conception rate after insemination depends on lactation number. Conception rate per lactation number weighed according to an average herd composition results in 62%. Oestrus detection rate is 70%. Probability of involuntary disposal is 12% in lactation 1 and increases to 23% in lactation 10.

Performance model

In Table A6.1 the base prices of milk, calves, replacement heifers and carcass weight are presented, together with the monthly deviation in prices. In Table A6.2 energy content and price of grass, silage and concentrates are presented. In summer (May-October) cows feed on grass and concentrates. In winter the ration consists of silage and concentrates.

Table A6.2 Energy content and prices of different kinds of feed

	Energy content (VEM)[a]	Price (US$/1000 VEM)
Grass	951	0.122
Silage	850	0.167
Concentrates	1045	0.194

[a] VEM = Dutch Feed Unit; 1000 VEM = 6.9 MJ NE_L

Table A6. 1 Base price and monthly deviations in prices of milk, calves, replacement heifer and carcass weight

	Base price	Monthly deviations in price (US$)											
	(US$)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Milk, 100 kg[a]	-1.61	2.06	+1.00	-0.39	-0.83	-2.50	-2.50	-2.50	-2.06	-0.39	2.94	+4.06	+3.89
Calves, kg[b]	5.86	0.66	-0.83	-0.92	-0.09	0.98	1.09	+1.14	+0.44	-0.04	-0.27	-0.4	-0.54
Replacement heifer	1444	-21	-32	-37	-25	7	+7	+15	+26	+24	+36	+11	+13
Carcass weight, kg[c]	3.56	-0.21	-0.13	0.03	+0.04	+0.18	+0.18	+0.13	+0.08	+0.06	-0.02~	-0.12	-0.17

[a] Prices of milk fat and protein are US$4.44 and 8.06 per kg respectively. Price of 100 kg of milk is based on the negative base price, the monthly deviation in base price and the price of fat and protein contents in 100 kg of milk. Mature equivalent milk production is set at 7750 kg of milk, 4.35% of fat, and 3.39% of protein.

[b] Refers to male calves. Base price for heifer calves is US$3.67.

[c] Refers to price of a kilogram of carcass weight of a first parity cow 210 days in lactation.

7

Dynamic programming to optimize treatment and replacement decisions

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Objectives

From this chapter the reader should gain knowledge of:

- the methodological aspects of treatment and replacement decisions in livestock
- the basic principles of dynamic programming to support these decisions

7.1 Introduction

Commercial livestock farms produce either products extracted from the animals over their lives (such as milk, eggs and wool), or the meat harvested at the end of the animals' lives (such as beef, pork and chicken), or both. Necessary inputs include feed and veterinary treatment. Decisions have to be made on the quality, quantity and timing of the feed and veterinary inputs. The product return to these inputs changes continuously over the life of the animals. Typically, productivity of the animals first increases and then declines with age. If the livestock enterprise is to be a continuing one, a decision must be made on when to replace breeding females.

Furthermore, in case of disease, farmers are frequently faced with the problem whether to treat or replace an affected animal. The cost-value trade-off is then important. Will the animal recover completely and will it reach its previous production level? If so, how long does it take before the animal is at its normal level again? Another important question in this respect is the repeatability of disease. All these factors have to be balanced before the farmer can make an appropriate treatment or replacement decision.

In section 2 of this chapter some methodological aspects of treatment and replacement decisions at the animal level are reviewed. In section 3, the technique of dynamic programming (DP), which can be used to optimize these multi-stage decisions, is introduced. Lastly, two DP-applications are presented, the first one being an application to dairy cows, and the second one involving sows.

7.2 Methodological aspects

The technique for determining optimal livestock replacement decisions relies on the

production function approach as explained in Chapter 2 and depends on the shape of the marginal net revenue curve (ie, the net revenue in each additional year, month or day of life), the characteristics of replacement animals, the discount rate and whether or not involuntary replacement takes place. The net revenues from not only the animals present in the herd but rather from the present and all subsequent (replacement) animals are to be maximized. This implies that an infinite planning horizon has to be considered in the marginal net revenue approach. For simplicity reasons assume that there is no discounting and involuntary replacement, and that net revenue is represented as a function of time (Figure 7.1).

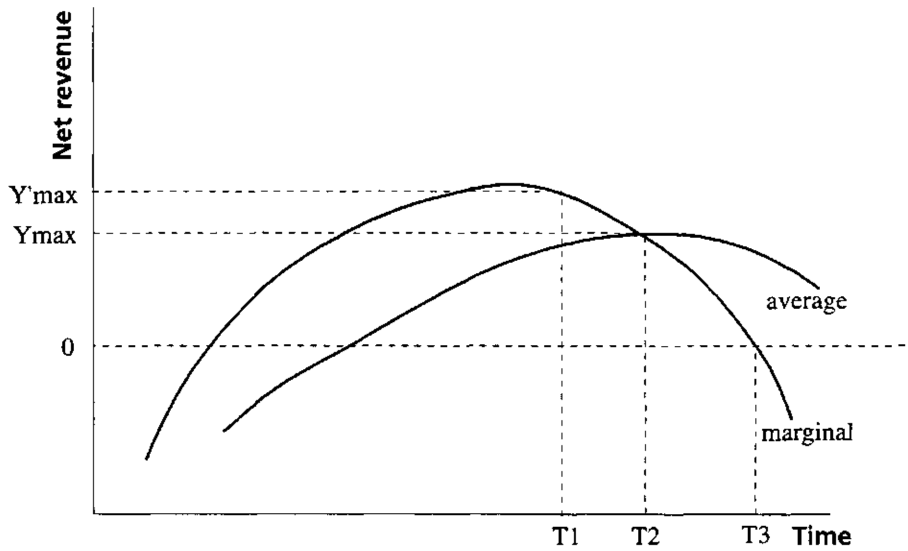

Figure 7.1 Determination of the optimal time for replacement in a situation without an alternative opportunity (T3), and in situations of identical replacement (T2) and nonidentical replacement (T1) (derived from Van Arendonk, 1985)

Furthermore, assume that the decision problem is how long the livestock unit is to be kept. The answer depends on the three opportunities available at the moment(s) at which the unit can be replaced.

- If there are no replacement animals available at the decision moment, the relevant objective is maximum net revenue, which corresponds with the optimal time for replacement T_3. This represents the situation in which there are no opportunity costs.
- If there are identical replacement animals available, the optimal time for replacement is T2. T2 corresponds with the time at which the marginal net revenue from the present animal(s) equals the expected maximum average net revenue from the subsequent replacement animal(s) (y_{max}). The maximum average net revenue from subsequent replacement animal(s), which is used to determine the optimal time, can be interpreted as the opportunity cost of postponed replacement.

- Lastly, if there are nonidentical (better) animals available, the optimal replacement time is T1. T1 corresponds with the time at which the marginal net revenue from the present animal(s) equals the expected maximum average net revenue from the subsequent nonidentical replacement animals (y'max).

When there is time preference of net revenue, comparison of expected costs and revenues should be made at the same point in time. This can be achieved by **discounting** future costs and revenues, as explained in Chapter 3 (section 5). When discounting is applied, the optimal time to replace is reached when the marginal net revenue from the present animal(s) is equal to the maximum annuity of expected net revenues from the subsequent replacement animal(s). In the latter value, the marginal net revenues and periods of time are weighed to allow for time preference. A higher discount rate can result in both later and earlier replacement, depending on the shape of the marginal net revenue curve.

The marginal net revenue technique is explained by a simple calculation model (ie, identical replacement, no discounting, but including involuntary disposal) for fictitious animals. In calculating the optimal lifespan for individual animals, the opportunity costs must be determined first. The calculation is based on the average performance of animals present in the herd, assuming this to be the best estimate for expected future net revenue of young replacement animals. Future revenues and costs are weighed with the probability of animal survival. The formula is:

$$ANR_j = (\Sigma_{i=1..j}\, p_i \times MNR_j) / (\Sigma_{i=1..j}\, p_i \times l_i)$$

where

- ANR_j = expected average net revenue per year;
- i = decision moment of retention or replacement ($1 \leq i \leq j$), which is at the end of period i;
- j = period, at the end of which an animal can be replaced;
- p_i = probability of survival until the end of period i, calculated from the moment at which the young animal starts its first production (end of period 0);
- l_i = length of period i (in years); and
- MNR_i = marginal net revenue in period i including a correction for change in slaughter value and financial loss associated with disposal.

In Table 7.1, the formula has been applied to fictitious animals. The price of a highly pregnant replacement animal is US$500. The average net revenue is maximal at the end of period 5 (at decision moment 5). The optimal moment for replacement with identical animals is also at the end of period 5: the economically optimal lifespan is the last period with a positive difference between expected marginal net revenue of the present animal and maximum average net revenue of its replacement.

Table 7.1 Calculation model for identical replacement of a fictitious animal (all monetary values in US$)

Decision moment i (yr)	Marginal net revenue[a]	Slaughter value	Financial loss at disposal	Marginal probability of disposal	Probability of survival until year i	Marginal net revenue[b]	Average net revenue	RPO
0[c]		500						0[h]
1	200	345	60	0.15	1.00	36[d]	36[f]	212[i]
2	285	380	85	0.20	0.85	303[e]	159[g]	157
3	320	390	88	0.25	0.68	308	199	86
4	325	375	90	0.30	0.51	283	213	27
5	305	350	93	0.40	0.36	243	216[j]	—
6	250	300	—	1.00	0.21+ 3.61[k]	200	215	—

[a] Between the end of period i-1 and i, excluding change in slaughter value and financial loss at disposal

[b] Between the end of period i-1 and i, including change in slaughter value and financial loss at disposal

[c] Young highly pregnant animal, about to start its first production

[d] 200 + (345 - 500) - (0.15 x 60) = 36

[e] 285 + (380 - 345) - (0.20 x 85) = 303

[f] (1.00 x 36) / 1.00 = 36

[g] (1.00 x 36 + 0.85 x 303) / (1.00 + 0.85) = 159

[h] 1.00 x (36 - 216) + 0.85 x (303 - 216) + .. + 0.36 x (243 - 216) = 0

[i] 0.85/0.85 x (303 - 216) + 0.68/0.85 x (308 - 216) + .. + 0.36/0.85 x (243 - 216) = 212

[j] opportunity cost

[k] total herd life

After an animal's optimal lifespan has been determined, the total extra profit to be expected from trying to keep her until that optimum, compared with immediate replacement, can be determined taking into account the risk of premature removal of retained animals. This total extra profit is called **Retention Pay-Off** (RPO) and is calculated as follows:

$$RPO_i = \Sigma_{j=i+1..r}\, p_j\, (MNR_j - ANR_{max} \times l_j)$$

where

RPO_i	= Retention Pay-Off at decision moment i;
r	= optimal moment for replacement;
p_j	= probability of survival until the end of period j, calculated from decision moment i;
l_j	= length of period j (in years);
MNR_j	= marginal net revenue in period j; and
ANR_{max}	= expected maximum average net revenue per year.

The RPO is an economic index, which makes it possible to rank animals according to their future profitability: the higher the RPO, the more valuable the animal. A value below zero means that replacement is the most profitable choice. RPO also represents the maximum amount of money that should be spent in trying to keep an animal in case of reproductive failure or health problems.

Applied to livestock, the marginal net revenue approach faces two specific problems:

- For the calculation of the opportunity cost of postponed replacement it must be assumed that all subsequent replacement animals are identical with respect to net revenues. This assumption makes it impossible to account - directly - for continuous genetic improvement and seasonal variation.
- Variation in expected performances of both present and all subsequent replacement animals is not taken into account.

Extension of the marginal net revenue approach to overcome these limitations results in what is called the **dynamic programming** (DP) technique. DP is considered a better and more flexible tool for determining treatment and replacement decisions in livestock, and is introduced in the next sections.

7.3 Brief introduction to dynamic programming

Dynamic programming (DP) is a mathematical technique which is especially of value in situations where a sequence of decisions has to be made, as is the case with livestock replace ment decisions. DP uses the repetitiveness of the decisions to save computation time. It depends on a deceptively simple but remarkably powerful principle. It is generally referred to as **Bellman's Principle of Optimality** (Bellman, 1957):

> An optimal policy has the property that, whatever the initial state and initial decision are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision.

In DP a **policy** is defined as a sequence of decisions taken at different **stages**. Consider the case of a finite horizon with N stages. At each stage the system can be described completely by a state variable S_n. The **states** are the various possible conditions in which the system might be (eg, pregnant or open) at that stage of the problem (eg, 3 months after parturition). The action to be taken at stage n is the decision variable, denoted by X_n. Finally, there is the **objective function**. This is defined for each stage and is the value of the function appropriate for that stage and all subsequent stages. In the deterministic dynamic programming model, where all the subsequent outcomes are known for certain, the value of the objective function is an expression of all the decision variables still to be taken together with the value of the current state variable. Suppose that $C_n(X_n)$ is the value of the objective between stages n and n+1 when action X_n is taken. Bellman's principle of optimality now permits a statement of the problem in terms of its optimal policy.

Choose X_n so that

$$f_n(S_n) = \text{Opt}\ \{C_n(X_n) + f_{n+1}(S_{n+1})\}$$

where S_{n+1} is a known function of S_n and X_n and Opt is minimizing or maximizing as appropriate.

The solution procedure in a DP-model usually begins from the most remote stage (as the form of the equations imply) and works backwards to the present. So, first $f_N(S_N)$ is determined, with N denoting the end of the planning horizon or the last stage. After that, the stage number n is decreased by one (ie, N-1), the next $f_{N-1}(S_{N-1})$ function is calculated by using the value for $f_N(S_N)$ that has just been derived during the previous iteration. This process keeps repeating until the model finds the optimal policy starting at the initial stage (n=1). The variable S_1 is the known initial state, and $f_1(S_1)$ is therefore the total objective which is to be optimized. At each stage the optimal decision is determined for all combinations of the state variables, which specify the state of the process (eg, age and production in case of livestock).

Consider the following DP-example about finding the least-cost path through the network shown in Figure 7.2.

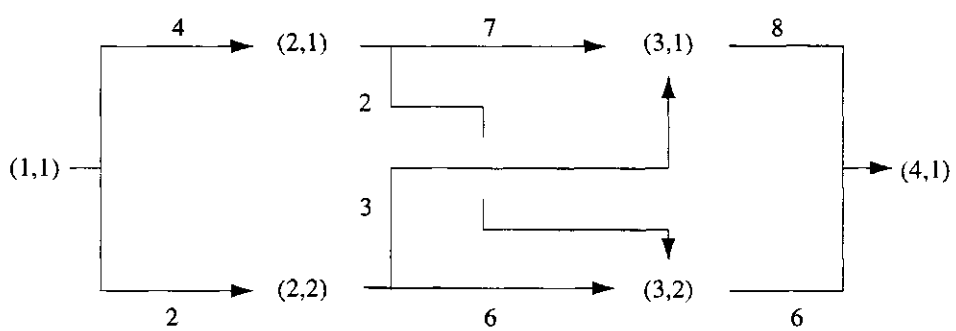

Figure 7.2 A least-cost network problem

Nodes have been designated (i,J_i), where i is the decision stage and J_i the state number. The optimal path must start at (1,1) and end at (4,1). Inter-node costs, or negative stage returns, are shown beside the linking decision arrows. A useful system for solving DP problems by hand is the preparation of a series of tables, one for each stage, starting with the final decision stage (Table 7.2). Each table has a row for each feasible state. Against each feasible state, the total cost to the end of the planning horizon is shown. Total cost is the sum of the stage costs and the optimal (least) costs to the planning horizon from the state accessed at the next stage. The last two columns of the table show optimal (least) total costs and the optimal decision associated with it. The procedure is demonstrated for the network problem of Figure 7.2 in Table 7.2.

The first row in Table 7.2 consists of the costs from node (4,1) to the end of the planning horizon (4,1), being zero. The second row consists of the cost of linking nodes (3,1) - (4,1) and (3,2) - (4,1), being 8 and 6 respectively. The third row consists of the cost of linking nodes (2,1) - (3,1) being 7 (stage cost) plus 8 (optimal cost between (3,1) and (4,1)), which equals 15. The second possibility here consists of the cost of linking nodes (2,1) - (3,2), being 2 plus 6 equals 8. The least cost of moving from (2,1) to (4,1) therefore is the minimum value of [15,8] = 8 via (3,2), as depicted in the last two columns of the third row. Other rows are determined in the same way.

Table 7.2 DP-solution procedure for the least-cost network problem

Node	**Costs to next node**		**Least costs**	**Optimal next node**
(4,1)	-		0	-
(3,1)	8 (4,1)		8	(4,1)
(3,2)	6 (4,1)		6	(4,1)
(2,1)	7+8 = 15 (3,1)	2+6 = 8 (3,2)	8	(3,2)
(2,2)	3+8 = 11 (3,1)	6+6 = 12 (3,2)	11	(3,1)
(1,1)	4+8 = 12 (2,1)	2+11 = 13 (2,2)	12	(2,1)

Table 7.2 shows that the least-cost path from (1,1) to (4,1) incurs a cost of 12. The least-cost path itself is found by tracking forward through the table. The table shows that (2,1) should succeed (1,1), and (3,2) should succeed (2,1). The optimal sequence of nodes therefore is (1,1) (2,1) (3,2) (4,1), with associated cost 4 + 2 + 6 = 12.

So far all costs and demands have been assumed to be known for certain (deterministic approach). Often this is not realistic, however. In livestock production, for instance, the unpredictable nature of the data should be taken into account. **Stochastic DP** requires the same fundamental assumptions as the deterministic approach. At each stage there is an explicitly known state variable S_n. The decision variable is again denoted by X_n, but whereas in the deterministic model S_n and X_n lead to a unique state variable S_{n+1} at the next stage, in stochastic DP there is a probability distribution, dependent on S_n and X_n, over the next state variable. The cost of the stage, $C_n(X_n)$, is usually assumed to be known without error. The equivalent form of the fundamental equation replaces the term $f_{n+1}(S_{n+1})$, which would otherwise be a random variable, with its expected value. This is the weighed average of all possible values of $f_{n+1}(S_{n+1})$, where the weights are the corresponding probabilities. This is written as $E[f_{n+1}(S_{n+1})]$. Now X_n is to be chosen so that

$$f_n(S_n) = \text{Opt}\ \{C_n(X_n) + E[f_{n+1}(S_{n+1})]\}$$

DP has the advantage of placing no restrictions on the nature of the functions used to specify the structure of the system. So, linear as well as nonlinear relationships can be included. 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, DP has been used most extensively in culling decisions in dairy cattle (see Van Arendonk, 1985; Kristensen, 1993; Houben, 1995) and in sows (Huirne, 1990).

7.4 Application of dynamic programming to replacement decisions in dairy cows

In the case of dairy cows, major revenues and costs differ with age and stage of lactation. Simultaneous consideration of all these - biological and economic - variables and their interrelationship is critical for making accurate replacement decisions. Decisions to replace individual animals are mainly based on economic rather than biological considerations under the condition that the size of the herd must remain constant. The farmer replaces a cow when a higher profit is to be expected from its replacement.

The simplest DP-formulation of the replacement problem has one state variable, lactation number S_n at stage n, and the decision option to keep the cow for at least one more lactation, or replace the cow with a heifer that is about to start its first lactation (Kennedy, 1986). The decision stage is the start of each lactation. Net returns over the lactation $R_n(S_n)$ depend on the cost of feed, the price of milk and the price of calves. If the decision is to keep the cow, and the lactation is successful, the state at stage n + 1 is 2. The return from the sale of the culled cow is denoted by $L_n(S_n)$, and the cost of the replacement heifer by C_n.

The lactation of the cow may be unsuccessful either because of failure due to low yield or a disease problem, or because of the death of the cow. If the lactation is unsuccessful, replacement is forced. In the case of forced or involuntary replacement because of failure, which has a probability of $PF(S_n)$, it is assumed that the stage net return is still $R_n(S_n)$. In the case of involuntary replacement because of death, which has a probability of $PD(S_n)$, it is assumed that the stage net return is also $R_n(S_n)$ but no return is realized from the sale of the cow. The probability of a successful transition from lactation S_n to $S_n + 1$ is therefore $(1 - PF(S_n) - PD(S_n))$ denoted by $PS(S_n)$. The discount factor is symbolized with δ. The recursive equation for maximization of the present value of expected net revenue is:

$$V_n(S_n) = \max\,[VK_n(S_n), VR_n(S_n)] \qquad (n = N-1,\ldots,1)$$

and

$$V_N(S_N) = L_N(S_N) \qquad (n = N)$$

where

$$\begin{aligned} VK_n(S_n) = {} & R_n(S_n) + \delta[PS(S_n)V_{n+1}(S_n+1) + \{PF(S_n) + PD(S_n)\} \\ & \times \{V_{n+1}(1) - C_{n+1}\} + PF(S_n)L_{n+1}(S_n+1)] \end{aligned}$$

for the decision **to keep** the cow for at least one more lactation; and

$$\begin{aligned} VR_n(S_n) = {} & L_n(S_n) - C_n + R_n(1) + \delta[PS(1)V_{n+1}(2) + \{PF(1) + PD(1)\} \\ & \times \{V_{n+1}(1) - C_{n+1}\} + PF(1)L_{n+1}(2)] \end{aligned}$$

for the decision **to replace** the cow with another one that is about to start its first lactation. After the optimal lifespan of a cow is calculated in this way, the model can be used to determine the Retention Pay-Off (RPO) for each individual cow:

$$RPO(S_n) = VK_n(S_n) - VR_n(S_n)$$

The above-mentioned equations must be extended and reformulated to obtain a real-life DP-application. State variables additional to lactation number which may be included are stage of lactation, moment of conception, month of calving, and perhaps most importantly, milk production level during previous and present lactations. Clearly, extending the number of state variables results in an increased complexity of the DP-equations.
Results of a dairy herd replacement model are presented below. It is a stochastic DP-model in which the state variables include lactation number, stage of lactation, milk production during previous and present lactations, and time of conception. The calculated RPO-values for typical - Dutch - conditions are given in Table 7.3, calculated for cows that have just become pregnant at three months after calving.

Table 7.3 Retention Pay-Off (RPO) of cows that have just become pregnant at three months after calving (in US$)

Lactation	**Relative production level of cow[a]**				
	80	**90**	**100**	**110**	**120**
1	-[b]	100	350	575	825
2	50	200	500	750	1075
3	75	225	525	800	1150
4	75	200	475	750	1075
5	50	150	400	675	975
6	25	100	325	575	875
7	-	25	225	450	725
8	-	-	100	325	575

[a] Relative to herd average at Mature Equivalent (%)
[b] An RPO-value below zero

As can be seen in Table 7.3, a first calving cow with an average production level (100%) has an RPO of US$350 at three months after calving. This is the financial loss should this cow be replaced for some reason. RPO also represents the maximum amount of money that should be spent in trying to keep her. RPO increases considerably for cows with higher production levels. A cow in third lactation with a relative production level of 120% has even an RPO of US$1150. The RPO of poor-producing animals declines sharply. A first lactation cow with a production level of 80% has a negative RPO, which means that replacement is the most profitable option. Should such a cow not be culled in its first lactation and should keep producing at 80% level, then its RPO from the second lactation onwards is just high

enough to remain in the herd until its 7th lactation.
Values shown in Table 7.3 are valid for cows that become pregnant at a normal moment in lactation. When this is not so, the farmer has to make a choice between the following (bad) options: (1) to re-inseminate the cow and accept the loss due to an increased calving interval, or (2) to replace the cow and accept the loss associated with premature disposal. In Table 7.4, results are presented for three different moments of decision: three, five and seven months after calving. Moreover, two different breeding outlooks are considered: (1) an optimistic outlook that assumes that the cow will have normal probabilities of conceiving in future lactations, and (2) a pessimistic outlook that assumes that the cow's fertility problems will recur.

Table 7.4 Critical production levels below which it is not profitable to inseminate empty cows

Decision moment[a]	Minimum calving interval (months)	Production level cow in lactation[b]							
		1	2	3	4	5	6	7	8
Optimistic breeding outlook									
3	12	86	86	88	90	92	94	98	102
5	14	90	90	92	96	98	100	104	110
7	16	96	96	98	102	104	108	112	118
Pessimistic breeding outlook									
3	12	86	86	88	90	92	94	98	102
5	14	100	100	100	102	104	106	108	114
7	16	120	114	114	116	116	118	120	124

[a] Months after calving
[b] Relative to herd average at Mature Equivalent (%)

The results in Table 7.4 indicate that from an economic point of view cows in their first lactation that produce less than 86% of herd average should not be inseminated any more at three months after calving. Assuming a normal distribution of production, and a phenotypic intra-herd standard deviation of milk yield of 12%, this result implies that 12 to 13% of first lactation cows should be culled for insufficient production capacity. At five months after calving, the production level should be at least 90% to justify insemination of non-pregnant animals, and the limit is 96% at seven months in lactation. So, from an economic point of view young animals with a high production level can be inseminated several times. For older cows, the critical production level is higher because of various factors, including the sharply increasing probability of involuntary disposal in future lactation and the continuous genetic increase in milk production. The critical production levels are strongly increased when recurrent fertility problems are to be expected (pessimistic breeding outlook), especially at moments of decision later in lactation. The influence decreases with a higher age of the cow concerned, because the remaining expected life has decreased, and hence the expected number of future calving intervals.

7.5 Application of dynamic programming to replacement decisions in sows

The application of DP to sows is very similar to that of dairy cows and, therefore, discussed only briefly. The simplest DP-formulation of the sow replacement problem has one state variable, parity number S_n at stage n, and the decision option to keep the sow for at least one more parity, or replace her with a replacement gilt that is about to start its first parity. The decision stage is the start of each parity, ie, the moment of weaning the piglets. Net returns over parity $R_n(S_n)$ depend on the feed and the price of feeder pigs sold. The return from the sale of the culled sow is denoted by $L_n(S_n)$, and the cost of the replacement gilt by C_n. The definition and probability of forced or involuntary replacement because of failure ($PF(S_n)$), of involuntary replacement because of death ($PD(S_n)$), and of a successful transition from parity S_n to $S_n + 1$ ($PS(S_n)$) are similar to the application to dairy cows. The recursive equations for maximization of the present value of expected net revenue, as presented in the previous section, are also valid for the sow replacement problem. To obtain a real-life DP-application, these DP-equations must also be extended. Additional state variables are moment of conception and piglet production level during the last and second last parity.

The results of a replacement model for sows are discussed. The state variables include parity number, litter size (number of pigs born alive) during the last and second last parity, and moment of conception. The average RPO-values for various sows at the first time of breeding after weaning are given in Table 7.5.

Table 7.5 Retention Payoff for sows pregnant at the first moment of conception after weaning (in US$)

Parity	Pigs born alive[a]	Relative production level of sow 50%	75%	100%	115%	130%
1	9.6	20	65	110	135	165
2	10.3	-[b]	40	110	150	190
3	10.8	-	20	90	135	180
4	11.1	-	-	70	115	155
5	11.2	-	-	50	90	135
6	11.1	-	-	30	70	110
7	11.0	-	-	15	50	90
8	10.9	-	-	5	35	70

[a] Parity-specific averages in the herd (= 100%)
[b] An RPO-value below zero

As could be expected a longer herd life is especially profitable for the better-producing sows. Table 7.5 also shows that strong selection in the earlier parities is economically not worthwhile. Even sows that produce 50% below average should not be culled on strictly economic grounds before their second parity. The key factor here is the low **repeatability** of litter size as a predictor of future performance of sows.

The critical production levels below which it is not profitable to (re)breed sows that fail to conceive are presented in Table 7.6. Results consider the optimistic breeding outlook only, assuming no expected repeatability of fertility problems in future parities.

Table 7.6 Critical production levels below which it is not profitable to breed empty sows

Parity	Pigs born alive[a]	Breeding 1	Breeding 2	Breeding 3	Breeding 4
1	9.6	40[b]	40[b]	66	85
2	10.3	47	57	77	98
3	10.8	58	70	93	115
4	11.1	69	88	110	134
5	11.2	82	101	125	144
6	11.1	88	110	133	150[b]
7	11.0	98	117	142	150[b]
8	10.9	100	124	147	150[b]

[a] Parity-specific averages in the herd (= 100%)
[b] Lower (40%) and upper (150%) production level used in the model

Average-producing sows (ie, 100%) in the first and second parity can be allowed at least three rebreedings before replacement becomes more profitable. As could be expected the critical production level below which rebreeding is not profitable any more strongly increases with a higher parity number. A third rebreeding is hardly ever optimal for sows in parities six to eight (critical production level equalling - at least - 150%).

Exercise

In Chapter 19 you can find an example on dynamic programming, in which the calculation of the optimal time of sow replacement is shown step by step. You have to use these results to calculate the RPO of the sows according to the explanation in this chapter. You can then change some input values for a sensitivity analysis to see how to use such a model for specific purposes. Finally, the model is extended by taking into account genetic improvement of the sows over time. The entire exercise takes approximately 45 minutes.

7.6 Concluding remarks

Dynamic programming is a flexible mathematical technique for determining the economically optimal treatment and replacement decisions for dairy cows and sows. Major **advantages** of DP include the possibility of allowing for variation in, and possible repeatability of traits. Both the risk that a high-producing animal (cow or sow) may have a low future production and the risk that an animal may be replaced with a low-producing replacement animal can, therefore, be taken into account. However, the DP-model easily becomes very large. This results in a high memory request and high computation costs. Kristensen (1993) developed a very efficient DP-algorithm, ie, the **Hierarchic Markov Process** (HMP), which can be used to optimize relatively large DP-models. Houben (1995)

used the HMP-approach to include mastitis incidence in the replacement model.
The calculated RPO-values for individual cows and sows can serve as useful guides for making replacement decisions. In case of health problems, the RPO-value of an animal represents the maximum amount of money that should be spent in trying to get her back to previous production levels.
The repetitive nature of the DP-algorithm makes it almost impossible to include culling reasons that are difficult to quantify, such as maternal characteristics. However, these can be taken into account using expert systems that are integrated with the DP-model. First promising prototypes for such systems have been made available for sows (Huirne, 1990).

References

Bellman, R.E., 1957. Dynamic programming. Princeton University Press, Princeton, NJ, 339 pp.

Houben, E.H.P., 1995. Economic optimization of decisions with respect to dairy cow health management. PhD-Thesis, Department of Farm Management, Wageningen Agricultural University, Wageningen, 146 pp.

Huirne, R.B.M., 1990. Computerized management support for swine breeding farms. PhD-Thesis, Department of Farm Management, Wageningen Agricultural University, Wageningen, 165 pp.

Kennedy, J.O.S., 1986. Dynamic Programming. Applications to agriculture and natural resources. Elsevier Applied Science, London, 341 pp.

Kristensen, A.R., 1993. Markov decision programming techniques applied to the animal replacement problem. Doctoral dissertation, The Royal Veterinary and Agricultural University, Copenhagen, 183 pp.

Van Arendonk, J.A.M., 1985. Studies on replacement policies in dairy cattle. PhD-Thesis, Department of Animal Breeding and Department of Farm Management, Wageningen Agricultural University, Wageningen, 126 pp.

8

Markov chain simulation to evaluate user-defined management strategies

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Objectives

From this chapter the reader should gain knowledge of:

- the characteristics of Markov chains
- the concepts and definitions of states
- the long-run properties of Markov chains

The method is introduced by two simplified examples and further illustrated with an application, simulating herd dynamics in sow herds in order to evaluate the effects of different management strategies on the technical and economic results of the herd.

8.1 Introduction

Markov chains are used to model the evolution of systems or processes over repeated trials or successive time periods. In animal health economics, Markov chain simulation has been used most extensively to evaluate the impact of alternative control strategies on the spread of disease (Carpenter, 1988; Dijkhuizen, 1989). Dynamic programming is also an application of Markov chains and is often used to determine the optimal insemination and replacement decisions for individual cows and sows (see Chapter 7).

Key issue of interest in Markov chain models is the study of events and sequential decision making under uncertainty. Intervals of time separate the stages at which events occur and decisions can be made, and the effect of a decision at any stage is to influence the transition from the current and succeeding state. Central to the theory of Markov chain models are the concepts of states and transitions. The distribution of the system or process over states at a certain moment can be derived from the distribution at the moment before and the transitions possible for each state. Characteristic is the Markovian property, implying that a transition from state i to state j depends only on the state currently occupied (Hillier & Lieberman, 1990).

8.2 Markov chains in general

A Markov chain model has two components: **states** and **transitions**. The Markov chain represents a system or process that moves between a number of states. The states may constitute a qualitative as well as a quantitative characterization of the system. If the present state is $S_n = i$, then there is a certain probability that the next state visited is $S_{n+1} = j$. This probability does not depend on the other states visited prior to entry into state i. In other words, the conditional probability of any future event, given any past event and the present state $S_n = i$, is independent of the past event and depends only upon the present state of the process. This is referred to as the **Markovian property** (Hillier & Lieberman, 1990). This principle can be illustrated with an example of a frog in a lily pond (Howard, 1971). The frog in this example always sits on a pad; it never swims in the water. From time to time the frog jumps into the air and lands on the same lily pad or on a different one. We are interested in the location of the frog after successive jumps. Let us assume the pond to have a finite number of lily pads, numbered from 1 to N, here from 1 to 3 (see Figure 8.1). The lily pads the frog can sit on represent the states in the Markov chain. The 'process' that moves from state to state is the frog. The 'transitions' are the jumps of the frog. If this situation is modelled as a Markov chain it means that the probability that the frog will jump from lily pad 1 to lily pad 2 only depends on the current state (lily pad 1) of the frog. The probability is independent of the lily pads that the frog occupied before it was on lily pad 1. The conditional probabilities $P\{S_{n+1} = j \mid S_n = i\}$ are called transition probabilities and are usually denoted by p_{ij}. If the transition probabilities p_{ij} are constant over time, they are stationary. Moreover, a Markov chain has a finite number of states and a discrete time parameter. Due to the Markovian property, a Markov chain is said to exhibit a lack of memory. However, by adding more states **memory** can be introduced into the model. If, for instance, in the frog example, the probability is dependent on the present pad occupied and on the one before that, the states will have to be reorganized. In that case we will have N^2 states, each representing a combination of two pads possible, representing pads occupied (see Figure 8.2).

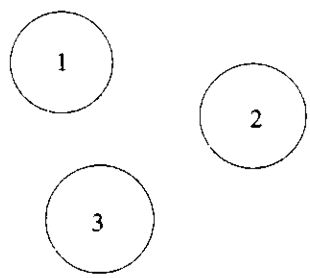


Figure 8.1 The lily pond

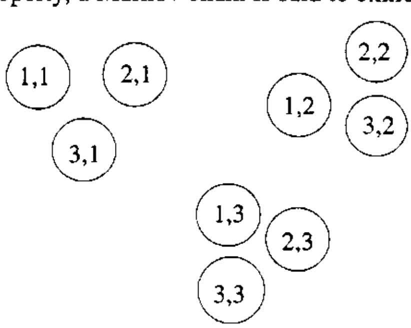


Figure 8.2 The lily pond with memory; (i,j); i = 1 ... 3, previous pad; j = 1 ... 3, present pad)

The distribution over states can be represented by a state vector X. A convenient notation for representing the transition probabilities is the transition matrix P, with elements p_{ij}. If the Markov chain consists of three states, the transition matrix is as follows:

$$P = \begin{bmatrix} p_{11} & p_{12} & p_{12} \\ p_{21} & p_{22} & p_{23} \\ p_{31} & p_{32} & p_{33} \end{bmatrix}$$

p_{13} represents the probability that the process which is in state 1 during period n will move to state 3 in period n+1. Each p_{ij} is a probability, and thus $0 \leq p_{ij} \leq 1$, for $1 \leq i, j \leq M$ (M equals the total number of states). The system or process must be in one of the m states after the transition from any state i and thus $\sum_j p_{ij} = 1$ for all i.
The state vector at time n+1, X_{n+1}, can be derived from the state vector at time n, X_n, and the transition matrix P: $X_{n+1} = X_n$ P. If transition probabilities are stationary, $X_{n+1} = X_0 P^{(n)}$. $P^{(n)}$ is denoted as the matrix of n-step transition probabilities. The elements of $P^{(n)}$, $p_{ij}^{(n)}$, are the conditional probabilities that the system or process, starting in state i, will be in state j after exactly n time steps. The n-step transition probability matrix can be obtained by computing the n^{th} power of the one-step transition matrix. So, $P^{(n)} = P\ P\ P\ P \ldots P = P^n$. So in fact, the initial state vector X_0 and the transition matrix P determine the state vector at each following moment. The characteristics of Markov chains will be illustrated with two simplified examples.

Sow replacement

In the first example, sow herd dynamics is modelled for a herd with a constant number of sows. After weaning litter i, a sow may be culled and replaced with a young sow that is about to have her first litter, or is retained and will produce the next litter. In the Markov chain the number of states is restricted to 3: (1) sow having litter 1, (2) sow having litter 2, and (3) sow having litter 3 or higher. The possible transitions for the Markov chain are from $S_n = i$ to $S_{n+1} = i+1$, when the sow is retained after weaning. If the sow is culled and replaced, the transition from $S_n = i$ to $S_{n+1} = 1$ will take place. All other transitions have probability zero. The non-zero transition probabilities are estimated from available data on several herds (Table 8.1).

Table 8.1 Data on number of sows culled and retained

Litter	Number of sows		Relative frequency	
number	culled	retained	culled	retained
1	216	864	0.2	0.8
2	184	552	0.25	0.75
≥3	614	1432	0.3	0.7

Thus, p_{11}, the probability that a sow that had litter 1 is culled equals 0.20. The resulting transition matrix is as follows:

$$P = \begin{bmatrix} 0.2 & 0.8 & 0 \\ 0.25 & 0 & 0.75 \\ 0.3 & 0 & 0.7 \end{bmatrix}$$

From P it is possible to derive $P^{(2)}$ by multiplying the one-step transition probability matrix by itself, $P^{(2)} = P^2 = P\,P$.

$$P^{(2)} = \begin{bmatrix} 0.24 & 0.16 & 0.6 \\ 0.275 & 0.2 & 0.525 \\ 0.27 & 0.24 & 0.49 \end{bmatrix}$$

$p_{11}^{(2)}$, one of the elements of $P^{(2)}$ is calculated as 0.2 x 0.2 + 0.8 x 0.25 + 0 x 0.3 = 0.24. $P^{(4)} = P^4 = P^2\,P^2$ and is given below:

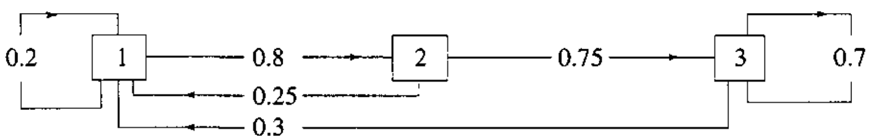
$$P^{(4)} = \begin{bmatrix} 0.264 & 0.214 & 0.522 \\ 0.263 & 0.210 & 0.527 \\ 0.263 & 0.209 & 0.528 \end{bmatrix}$$

The transition matrices presented above are used to derive the state vector at n=1, n=2 and n=4. In the initial state vector X_0, all 100 animals in the herd are sows that are about to have the first litter (X_0 = {100,0,0}). The state vectors at different time periods are given in Table 8.2.

Table 8.2 State vector X at different time periods n (X0Pn)

State	State vector			
	X_0	X_1	X_2	X_4
1	100	20	24	26.4
2	0	80	16	21.4
3	0	0	60	54.0

Another type of representation of a Markov chain is a transition diagram, which, for this example, is as follows:



Spread of a disease

In the second example, the spread of a certain disease among animals in a herd is modelled. Susceptible animals at time n can become infected at n+1 with a probability of 0.40. The infected animals in time period n+1 become immune at time period n+2 (probability 0.80), or die owing to the disease in time period n+2 (probability 0.20). The Markov chain consists of four states, (1) uninfected animals, (2) infected animals, (3) animals immune after infection, and (4) animals that died after infection. The transition matrix P is as follows:

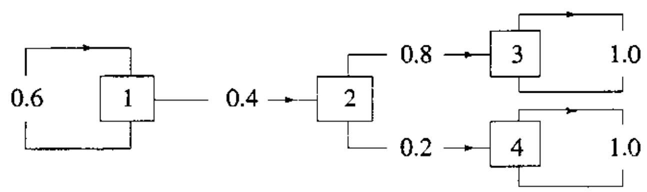
$$P = \begin{bmatrix} 0.6 & 0.4 & 0 & 0 \\ 0 & 0 & 0.8 & 0.2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

From P, $P^{(2)}$ and $P^{(4)}$ can be derived in the same way as was done in the first example.

$$P^{(2)} = P^2 = P\,P = \begin{bmatrix} 0.36 & 0.24 & 0.32 & 0.08 \\ 0 & 0 & 0.8 & 0.2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$P^{(4)} = P^4 = P^2\,P^2 = \begin{bmatrix} 0.130 & 0.086 & 0.627 & 0.157 \\ 0 & 0 & 0.8 & 0.2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

A graphical representation of the Markov chain can be produced by drawing the transition diagram:



8.3 Concepts and definitions of states

The transition probabilities associated with the states play an important role in the study of the system modelled by the Markov chain. Before describing the special properties of Markov chains, some concepts and definitions concerning states are presented.

State j is said to be **accessible** from state i if $p_{ij}^{(n)} > 0$ for some $n \geq 0$. All states of a Markov chain are accessible when there is a value of n for which $p_{ij}^{(n)} > 0$ for all i and j. In the first example, all states are accessible, since $p_{ij}^{(2)} > 0$ for all i and j. In the second example, state 1 is not accessible from state 2, as can easily be derived from the transition diagram. Also, in the n-step transition matrix, element $p_{21}^{(n)}$ equals 0 for all n. However, state 2 is accessible from state 1.

States i and j are said to **communicate** when state j is accessible from state i, and state i is accessible from state j. In the first example, all states communicate; in the second example, none of them do. In general:

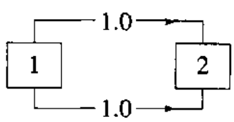
- any state i communicates with state i, since $p_{ii}^{(0)} = 1$;
- if state i communicates with state j, then state j communicates with state i; and
- if state i communicates with state j, and state j communicates with state k, then state i communicates with state k.

The states of a Markov chain can be divided into one or more disjoint **classes**. Two states that communicate always belong to the same class. A class may consist of a single state only. If all states in a Markov chain communicate, as in the first example, there is only one class and such a Markov chain is said to be irreducible. The second example contains 4 classes; all states form a separate class.

States differ in the probability whether or not a process, starting in state i, will ever return to state i. This probability is denoted by f_{ii}. For a **recurrent** state, f_{ii} equals 1. If $f_{ii} < 1$, a state is called **transient**. A special case of a recurrent state is an **absorbing** state. For an absorbing state, the one-step transition probability p_{ii} equals 1; once a process enters the state, it cannot leave it again.

All states in a class are either recurrent or transient, and therefore a class is denoted as recurrent or transient. Each finite-state Markov chain consists of at least one recurrent class of states. The first example consists of one recurrent class of states. The second example has two transients classes (1 and 2) and two recurrent classes (3 and 4). Once a recurrent class is entered, the process will never leave it again. Once a process leaves a transient class, the process will never enter it again. This can easily be inferred from the transition diagram in the second example.

The **period** of a state is defined to be the integer t (t > 1), such that $p_{ii}^{(n)} = 0$ for all values of n other than t, 2t, 3t, ..., and t is the largest integer with this property. In the two examples, there are no states with a period. In the following Markov chain, the transition diagram of which is presented, all states have period 2.



The proof that the Markov chain contains period 2 follows from the single-step and multi-step transition matrices:

$$P = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} = P^{(3)} = P^{(5)} \text{ etc.}$$

$$P^{(2)} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} = P^{(4)} = P^{(6)} \text{ etc.}$$

Thus, $p_{ii}^{(n)} = 0$ for n=1, 3, 5 etc. and $p_{ii} > 0$ for n=2, 4, 6 etc.

8.4 Long-run properties of Markov chains

For the first example, the four-step transition matrix was presented earlier. This transition matrix can be used to derive $P^{(8)}$ (= P^4 P^4).

$$P^{(8)} = \begin{bmatrix} 0.263 & 0.211 & 0.526 \\ 0.263 & 0.211 & 0.526 \\ 0.263 & 0.211 & 0.526 \end{bmatrix}$$

Because all three rows are similar, the probability of being in state j after 8 weeks seems to be independent of the initial state vector. If initially all sows are in state 1 ($X_0 = \{100, 0, 0\}$), the state vector 8 weeks later will be $X_8 = \{26.3, 21.1, 52.6\}$. If the initial state vector X_0 had been {33.3, 33.3, 33.3}, X_8 would also have been {26.3, 21.1, 52.6}.
$P^{(8)}$ can be used to calculate $P^{(16)}$. All entries in $P^{(16)}$ are equal to those in $P^{(8)}$. In case of an irreducible Markov chain, as in the first example, $\lim_{n\to\infty} p_{ij}^{(n)} = \pi_j$ exists and is independent of i. The π_js are called the **steady-state probabilities** of the Markov chain. The term steady-state probability means that the probability of finding the process in state j after a large number of transitions is independent of the initial probability distribution defined over the states and tends to the value π_j. Steady-state probabilities do not imply that the process settles in one state. The process continues to make transitions from state to state (the transition probability from state i to state j is still p_{ij}).
If the distribution over states has reached the steady-state distribution represented by the $_j$s at time n, the distribution over states at time n+1 is the same. This characteristic can be used to derive directly the vector Π containing the stationary probabilities π_j, instead of making all the necessary time steps. The following set of equations needs to be solved: $\Pi = \Pi$ P and $\sum_j \pi_j = 1$. For the first example these include:

$$\pi_1 = 0.2\,\pi_1 + 0.25\,\pi_2 + 0.3\,\pi_3$$
$$\pi_2 = 0.8\,\pi_1$$
$$\pi_3 = 0.75\,\pi_2 + 0.7\,\pi_3$$
$$1 = \pi_1 + \pi_2 + \pi_3$$

Solving the last four equations provides the simultaneous solutions: $\pi_1 = 0.263$, $\pi_2 = 0.211$ and $\pi_3 = 0.526$, which are the results that appeared before in matrix $P^{(8)}$.

When a Markov chain consists of more than one recurrent class of states, the steady-state distribution or limiting distribution over states is no longer independent of the initial state vector X_0. So, $\lim_{n\to\infty} p_{ij}^{(n)} = \pi_{ij}$ and is no longer independent of i. For the second example, the transition matrix with the steady-state probabilities ($P^{(\infty)}$) is as follows:

$$P^{(\infty)} = \begin{bmatrix} 0 & 0 & 0.8 & 0.2 \\ 0 & 0 & 0.8 & 0.2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

If in the initial state vector all animals are susceptible ($X_0 = \{100,0,0\}$), ultimately 80% of the animals will be immune and 20% will have died. When initially 50% of the animals are immune and 50% susceptible, then in the long run 90% of the animals will be immune and 10% will have died owing to the disease. These figures can also be derived from the transition diagram.

If states i and j are recurrent states belonging to different classes, then $p_{ij}^{(n)} = 0$ for all n. In the second example, states 3 and 4 are recurrent states belonging to different classes. Therefore, $p_{34}^{(n)} = 0$ and $p_{43}^{(n)} = 0$, for all n. State j is a transient state, when $\lim_{n\to\infty} p_{ij}^{(n)} = 0$ for all i. In the second example, states 1 and 2 are transient states; $\lim_{n\to\infty} p_{i1}^{(n)} = 0$ and $\lim_{n\to\infty} p_{i2}^{(n)} = 0$, for all i (see matrix above).

Exercise

With the computer case on Markov chains (in Chapter 19) you can practise the principles of Markov chains: setting up a transition matrix and defining whether the different states are recurrent, transient or absorbing You will also see an example of calculating the steady state in one step, as explained in section 8.4. After the introduction, an example with mastitis is worked out. There are different strategies of changing the current mastitis situation in the herd. You have to use the Markov chain approach to determine which strategy is the best. Hereafter, the Markov chain is extended with dynamic transition rates, indicating that the probability of infection is dependent on the number of animals infected in the previous period (this is a more realistic, but also a more complicated way of using Markov chains). The exercise takes approximately 45 minutes.

8.5 Simulation of herd dynamics

A dynamic probabilistic model was developed in order to calculate the effects of different management strategies with respect to production, reproduction and replacement on the technical and economic results of an individual sow herd (Jalvingh, 1993). Central in the model is the simulation of herd dynamics using a modified Markov chain.

8.5.1 Description of the Markov chain model

The sow herd is described in terms of states the animals can be in and the possible transitions between states and the corresponding probabilities. Taking into account model objectives, time interval between transitions is set at 1 week. The states that are included are related to the (re)production cycle of the sows. Table 8.3 presents the state variables that were used to describe the states from weaning to weaning. To cut down the number of states per cycle, the number of state variables used in the second part of the gestation period is reduced. The total number of states from weaning to weaning is 156. Furthermore, the state variable 'cycle number' is used to represent sows of different ages, varying from 1 to 10.

Table 8.3 Possible values of the state variables used to describe states within a cycle of the sow (from weaning to weaning). State variables used are dependent on stage in cycle. Time unit in the model is 1 week.

	State variables[a]					
Stage in cycle	i^b	j	k	l^b	m^b	n
Weaning - insemination	1-3					
Insemination - halfway gestation		0-6		1-4	1-12	
Halfway gestation - farrowing		7-16				0-1
Farrowing - weaning			1-4			

[a] The following state variables are used:

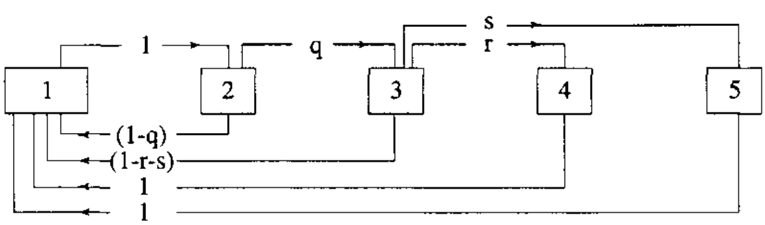
i: time after weaning;
j: time after insemination;
k: time after farrowing;
l: number of inseminations performed during this cycle;
m: interval weaning - insemination;
n: pregnant or not.

[b] Upper limit number of classes depends on user-defined input values; given number is maximum.

By adding extra state variables to the model the production history of the sows can be taken into account. Production level at last farrowing and production level at second last farrowing are included as state variables. So, when taking decisions for individual sows, productivity of the sow can be taken into consideration. Both these extra state variables vary from 4 to 16 pigs born alive. The maximum number of states in the model is 156 x 10 x 13 x 13 = 263 640. In this chapter, the state variables referring to production level will not be used, leaving a model with 156 x 10 = 1560 states.

For each state mentioned above, the probability of making the next transition to each other state has to be specified. Herd dynamics is a result of the interaction between biological variables and management strategies. Therefore, transition probabilities are dependent on input parameters referring to **biological variables** on the one hand (eg, pregnancy, oestrus detection and involuntary culling rates) and **management strategies** on the other (eg, insemination and replacement strategies). Three categories of transition probabilities are considered: (1) reproduction, (2) involuntary disposal, and (3) production level.

At each time step, individual animals are either retained or culled. If a sow is culled, it is replaced by a replacement gilt (6 months old). A replacement gilt can stay in the herd until it is culled and replaced or until it has reached the maximum allowable litter (10 in this case). The following transition diagram is a simplified representation of the Markov chain, which has the same characteristics as the sow herd model. Sows are either retained or culled. If a sow is retained, she has the possibility of going to more than one state (eg, in case of inseminated and not inseminated). State 1 represents the replacement gilt.



The transition diagram shows that all states communicate. Therefore, and when transition probabilities are stationary, the steady-state probabilities are independent of the initial state vector. No matter how the animals were initially distributed over the states, the limiting distribution over states is always the same. The limiting distribution is in fact equal to the distribution of a replacement gilt over all states during her life. The steady-state probabilities are recalculated to represent a herd with a certain size. Due to the ageing of sows, only a few transitions are possible for each state. The transition matrix has a great many rows and columns, containing per row, therefore, only a couple of non-zero entries. The Markov chain has been programmed to allow for these typical characteristics.

To evaluate the consequences of changes in herd dynamics, several technical and economic results are derived from the distribution over states. Some variables are derived directly from the steady-state distribution, such as number of litters per sow per year and percentage of reinseminations. For other variables additional technical and economic variables are needed, as in the case of returns (eg, price of piglets and culled sow) and costs (eg, price of feed and replacement gilt).

8.5.2 Model results

For a basic situation representing typical Dutch herds, the technical and economic results of the corresponding steady-state herd were determined (herd I). Appendix 8.1 presents the major technical and economic input variables. The steady-state herd was also determined if pregnancy rates were at a 20% lower level (herd II), and when oestrus detection rate after first insemination was at a 20% lower level (herd III). The results of the three steady-state herds are presented in Table 8.4.

Table 8.4 Major technical and economical results of different steady-state herds

	Herd		
	I[a]	II[a]	III[a]
Technical results			
Average number of sows	130	130	130
Litters per sow per year	2.32	2.17	2.30
Pigs born alive per litter	10.6	10.5	10.6
Pigs sold per sow per year	21.0	19.5	20.8
Culling rate sows (%)	49.3	69.2	51.7
Reinseminations (%)	11.5	23.7	10.0
Economic results (US$ per sow per year)			
Returns			
- piglets sold	1224	1138	1216
- sows and gilts culled	119	162	125
Costs			
- replacement gilts	152	214	159
- feed sow	328	329	328
- feed piglets	264	246	263
Gross margin	599	511	589
Gross margin herd (US$)	77872	66416	76641

[a] Herd I: basic situation; Herd II: pregnancy rates at 20% lower level; Herd III: oestrus detection after first insemination at 20% lower level.

In the basic situation (herd I), the number of litters per sow per year is 2.32, the number of pigs sold per sow per year is 21.0 and the annual culling rate in sows is 49.3%. Resulting gross margin per sow per year is US$599. If pregnancy rates are at a 20% lower level (herd II), percentages of reinseminations and annual culling rate increase. This results in a reduction in number of litters per sow per year (minus 0.15) and number of pigs sold per sow per year (minus 1.5). The reduction in gross margin is US$88 per sow per year. If oestrus detection rate after first insemination is at a 20% lower level (herd III), fewer sows that have been inseminated but have not become pregnant will be seen in oestrus again. Since oestrus detection rate before first insemination and pregnancy rate are still at a high level, the effects on the results are minimal. The number of litters per sow per year has decreased (minus 0.02). Gross margin per sow per year is US$9 lower than in the basic situation.

The model has been used to compare different insemination strategies (when to stop inseminating if a sow fails to conceive). Besides looking at the herd structure in its stationary state, herd dynamics can be studied over time. The model can be used to study how a herd approaches a new steady state, for instance, when some transition probabilities are modified.

The modelling approach developed for swine was also applied to dairy cattle. Transitions take place at monthly intervals. Month of calving was included as an additional state variable, and, therefore, the period of all states in the Markov chain is 12. The dairy herd model also focuses on the evaluation of different calving patterns, and on the comparison of different strategies to actually change the calving pattern of the herd (Jalvingh, 1993).

8.6 Concluding remarks

In animal health economics, Markov chains are especially used to simulate contagious disease control. The probability of becoming infected is often assumed to depend on the fraction of herds or animals being infected during the previous time period. In that case, the property of stationary transition probabilities does not hold any more. Such a modified version of the Markov chain approach is called the State Transition approach (Dijkhuizen, 1989).

The (modified) Markov chain approach is in fact a stochastic model using probability distributions, taking into account uncertainty about the future behaviour of the system. Another approach to simulate disease spread and herd dynamics is stochastic simulation using random elements (ie, Monte Carlo simulation), as is described in Chapter 9. The Markov chain approach provides the **expected value** of the results by carrying out a single run. In the approach using random elements multiple runs are needed to obtain a reliable estimate of the average results. An advantage of the multiple runs is the information that can be obtained about the **standard deviation** of the results, making statistical tests and non-neutral risk analysis possible. An advantage of the approach using probability distributions instead of random elements is that sensitivity analyses can easily be carried out. The differences between stochastic simulation using probability distributions and using random elements were described extensively in Chapter 5.

References

Carpenter, T.E., 1988. Microcomputer programs for Markov and modified Markov chain disease models. Preventive Veterinary Medicine 5: 169-179.

Dijkhuizen, A.A, 1989. Epidemiological and economic evaluation of foot-and-mouth disease control strategies in the Netherlands. Netherlands Journal of Agricultural Science 37: 1-12.

Hillier, F.S. & Lieberman, G.J., 1990. Introduction to operations research. McGraw-Hill, New York, 954 pp.

Howard, R.A., 1971. Dynamic Probabilistic Systems. Volume I: Markov Models. John Wiley & Sons, New York, 577 pp.

Jalvingh, A.W., 1993. Dynamic livestock modelling for on-farm decision support. PhD-Thesis. Department of Farm Management and Department of Animal Breeding, Wageningen Agricultural University, Wageningen, 164 pp.

Appendix 8.1

Table A8.1 Basic values of biological input variables that determine transition probabilities concerning reproduction

Variable	Basic value
Distribution of first observable oestrus	
week 1 after weaning	80
week 2 after weaning	20
week 3 after weaning	0
Oestrus detection rate (%)	
before first insemination	98
after first insemination	90
Farrowing rate (within cycle) (%)	
after insemination 1	85
after insemination 2	65
after insemination 3	50
after insemination 4	40
Distribution over 'reasons' for not conceiving	
in oestrus after 3 weeks	90
in oestrus after 6 weeks	0
abortion	7
not pregnant in farrowing house	3

Table A8.2 Cycle-specific input values concerning transition probabilities and technical and economic results

Cycle number	Involuntary disposal (%)	Pigs born alive	Piglet mortality (%)[a]	Live weight sow (kg)
0	10			140
1	2	9.6	13.0	140
2	8	10.3	12.0	160
3	8	10.8	13.0	175
4	7	11.1	13.0	188
5	9	11.2	14.0	196
6	11	11.1	14.0	200
7	13	11.0	14.0	200
8	15	10.9	15.0	200
9	17	10.8	15.0	200
10	18	10.7	15.0	200

[a] Piglet mortality rate before weaning; mortality rate after weaning: 1.5%.

Table A8.3 Economic input variables and their basic values

Variable	Basic value
Feeder pig price (US$/head)	58
Feed price (US$/100 kg)	
gilts and non-lactating sows (EV/kg[a] = 0.97)	25
lactating sows (EV/kg = 1.03)	25
pigs	42
Slaughter value (US$/kg)	
cycle 0	1.40
cycle 1	1.28
cycle 2 and higher	1.22
Price replacement gilts (US$/head)	278

[a] EV/kg = 1 = 8786 kJ net-energy for fat production.

9

Monte Carlo simulation to model spread in management outcomes

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Objectives

From this chapter the reader should gain knowledge of:

- the differences between information systems and simulation models
- the principles of Monte Carlo simulation
- the potential use of a generic livestock generator

Monte Carlo simulation is further illustrated with an application in dairy and one in swine farming.

9.1 Introduction

A major goal of livestock farmers is to consistently maximize the short-term profitability of the animal enterprise while maintaining the breeding livestock herd as a viable production unit which will guarantee long-term economic success. This requires that attention be paid to resource use, cash flow, debt load and income tax treatment, as well as to the population dynamics of the herd. In order to be confident of delivering appropriate and cost-effective care and advice, it is essential that farmers and advisers have a full understanding of the ramifications and possible outcomes of proposed actions.

The sheer enormity of the task of manually computing the outcome of numerous possible management strategies has in the past discouraged all but the most elementary analyses. The growing availability of low-cost computing power has put powerful analytical tools at the fingertips of researchers, farm managers and veterinarians. In this chapter, it is demonstrated how a standard personal computer can be programmed to simulate and analyse the performance of livestock production systems, and hence to predict the likely outcome of various management strategies as an aid to the decision-making process, through so-called Monte Carlo simulation.

9.2 Information systems and computer modelling

It is useful to draw some distinctions between information systems and simulation models. The primary purpose of an information system is to provide the necessary data to assist the decision-making process for the management of an enterprise (in this case livestock production), not only for the control of current operations, but also for the planning of future activities. Information systems facilitate the flow and interpretation of data, whereas simulation models extend the value of the data collected. Models can be linked to information systems to provide systematic procedures for the synthesis of management options based on an analysis of the current situation. In this manner, the information collection system serves to provide parameter estimates for the model. These estimates are updated as new information is acquired.

Modelling allows key features of a system to be defined and represented, so that the behaviour of the system under various hypothesized conditions can be evaluated. Models have been developed as a means of exploring the interactions of disease processes, environment and animal production systems. Systems analysis is employed to identify the important components of each subsystem, and to formulate mathematical relationships which adequately describe the biological relationships between those components. The relationships between pairs of variables can be established experimentally; however, the multiple interactions of the components of each subsystem and the interactions of the various subsystems comprising the whole system have been difficult to conceptualize - let alone investigate.

The use of computer simulation techniques provides the added dimension of time. As well as permitting the study of these complex interrelationships from a static viewpoint, the behaviour of the system and its subsystems may be explored as they change dynamically. In the study of animal health and production such techniques afford improved ways of interpreting information to improve decision making, as the ramifications of veterinary intervention or changes in management levels are often not apparent until many months after the action has been taken.

Perhaps one of the main advantages of using computer simulation techniques as an adjunct to the classical experimental approach is the ability to compress the passage of time. Computer models enable the experimenter to simulate many years of activity within a population under different conditions in a few hours. Moreover there can be total control over exogenous variables, a feature which can be invaluable - especially if interest lies in the behaviour of the system under conditions which cannot reliably be reproduced experimentally. For instance, instead of waiting many years for a drought to occur, research may be carried out under simulated drought conditions, and the technology developed to deal with adverse conditions in time to avert disaster.

Another application might be to simulate the potential effectiveness of some powerful drug or vaccine which has not yet been evaluated under field conditions. If the simulation exercise were to include an economic analysis of the benefits of employing such a drug, the benefits could be weighed against the cost of development, testing and production. Only if the cost-benefit analysis appeared favourable would the continuation of the project be recommended. Using a Monte Carlo simulation model, Morris (1976) found that the development of a vaccine for a single pathogen of bovine mastitis could not be justified economically as a practicable alternative to teat dipping and dry cow treatment.

Despite the apparent power that simulation modelling gives the experimenter, it is important to bear in mind that one of the most important requirements of a simulation model is simplicity in the eyes of the user. This is because decision makers will not have confidence in the predictive ability of a model if they do not understand its mechanisms. Input and output variables must, therefore, be expressed in terms and units familiar to those who are to use the model.

Besides their uses in aiding decision making, models can also have an important role in teaching and research as means of acquiring a deeper understanding of a system. The process of model building often serves to expose the gaps in knowledge. One of the sobering lessons that the research worker almost invariably learns from the modelling exercise is that certain questions that are crucial to the comprehensive understanding of the system have never been asked, let alone answered experimentally, while other questions which are notable only for their trivial influence on the behaviour of the system have been investigated repeatedly.

9.3 Monte Carlo modelling: basic principles

Monte Carlo modelling is so called because the occurrence and timing of each simulated event is based on **chance** as in a casino. A virtue of this approach is that the structure of the model is totally under the control of the research worker and can evolve in complexity as the understanding of the modeller grows. The model operates by creating a starting population within the computer which mimics the population of interest in all relevant respects. What happens to the population over time in terms of reproduction, production and disease is determined by taking random observations on suitably-defined probability distributions.

The **'random' numbers** used to generate the process are samples on a rectangular (or uniform) distribution R(0,1). They are termed pseudo-random numbers because they are produced by the computer as a very long string of numbers which will eventually repeat itself. The periodicity, or number of numbers before the string begins to repeat itself for the random number generator, should be large enough to prevent a repetition of the random number sequence during a single simulation run. The nature of the random number string is determined by a 'seed number' used to initiate the process. A particular seed will always generate the same string of random numbers, so the seed number for each simulation run should be created in a manner which ensures the independence of successive runs.

Most computer language run-time libraries contain a procedure or function called RANDOMIZE, which is a random number generator initialiser. Each time RANDOMIZE is invoked, the date and time stored by the computer's operating system is read. RANDOMIZE interprets the date and time as a number of seconds since a reference date and time. This large number is manipulated to produce an integer between 1 and 65535 which, in turn, is passed to the random number generation function as the seed which initiates the random number generator for that simulation. Each time the random number generator is called upon by the program, it returns the next random integer in the pseudo-random sequence. This number will be a random observation between 0 and 32767 on a rectangular (uniform) distribution, and can readily be converted to an observation on R(0,1). Various functions have been written and tested to convert the stream of pseudo-random integers into different probability distributions, which are sampled at various times in the model. The distribution may be discrete, such as the Poisson or the binomial distribution. Sampling may also be carried out on continuous distributions such as the normal, lognormal or exponential distribution (see also Chapter 18). Methods used to generate pseudo-random numbers have been described by a number of authors of texts on simulation methods. Shannon (1975) and Payne (1982) are useful references which provide source code for generating random observations on a number of common mathematical distributions. Anderson (1974) provides a useful discussion on the use of seed numbers.

An observation on the uniform distribution can be used to determine whether an animal becomes pregnant to a particular mating, given a long-term probability of 0.40. A random number between zero and one on a rectangular distribution is generated by the computer. If the random number is greater than 0.40, then the animal is considered not to have conceived. If the random number is less than or equal to 0.40, the event is deemed to have happened and the animal is considered to be pregnant. The model may go on to determine whether the animal terminates the pregnancy by aborting or giving birth to offspring.

The distribution selected for each test will depend upon the nature of each biological process being simulated. If none of the mathematically-defined distributions is appropriate, then a purely empirical distribution may be derived from field data. Because they are based on probabilities rather than fixed calculations, it is necessary to execute at **multiple runs** of a Monte Carlo model to estimate the average outcome and the variability between runs.

9.4 ORACLE: a generic model of livestock reproduction and production

Livestock production systems provide excellent subjects for computer modelling. Evaluations of management changes on economic performance and herd demographics are extremely complex due to the multiple interactions that exist between various factors. Prediction of effects of a change in management strategies on net farm income may be quite misleading if they are based on simplistic assumptions about the effects of the actions taken. Further, one must be careful to distinguish between short- and long-term effects, and to allow for time lags between management intervention and improvement in performance.

A classic example is that of improving reproductive performance in dairy herds: a one-year partial budget of the proposed improvement can be produced to show an increase in annual net farm income, mainly due to a reduced calving interval and a reduced replacement rate. However, the true situation may be that in the first year of improved performance, net farm income decreases temporarily due to fewer animals being culled because of reproductive failure. Net farm income will improve during the following year when the benefits of a shortened calving interval and a reduced replacement rate are realized.

Disease control programs, such as the adoption of teat dipping and dry cow therapy must often be practised for at least a year before net farm income can be improved significantly. With the capability of demonstrating patterns of changing performance through time, simulation modelling offers a means of better understanding the complexities and temporal relationships involved in the management of livestock herds, and can provide a vehicle for explaining the likely consequences of veterinary and managemental intervention to the owners of such herds.

9.4.1 The generic livestock generator

Just as Blackie and Dent (1974) advocated the use of a species-specific skeleton model that could be coupled with data from an individual farm, it is possible to take the concept a step further and design a species-independent skeleton model that can be coupled with parameters which are species-specific to produce simulation models capable of predicting the characteristics of reproductive events in a number of mammalian species.

The outline of the **'generic livestock generator'** is shown in Figure 9.1. When considering the sequencing of events in the reproductive and productive cycles of the mammalian species kept as food animals, it can be seen that certain similarities exist. Before giving

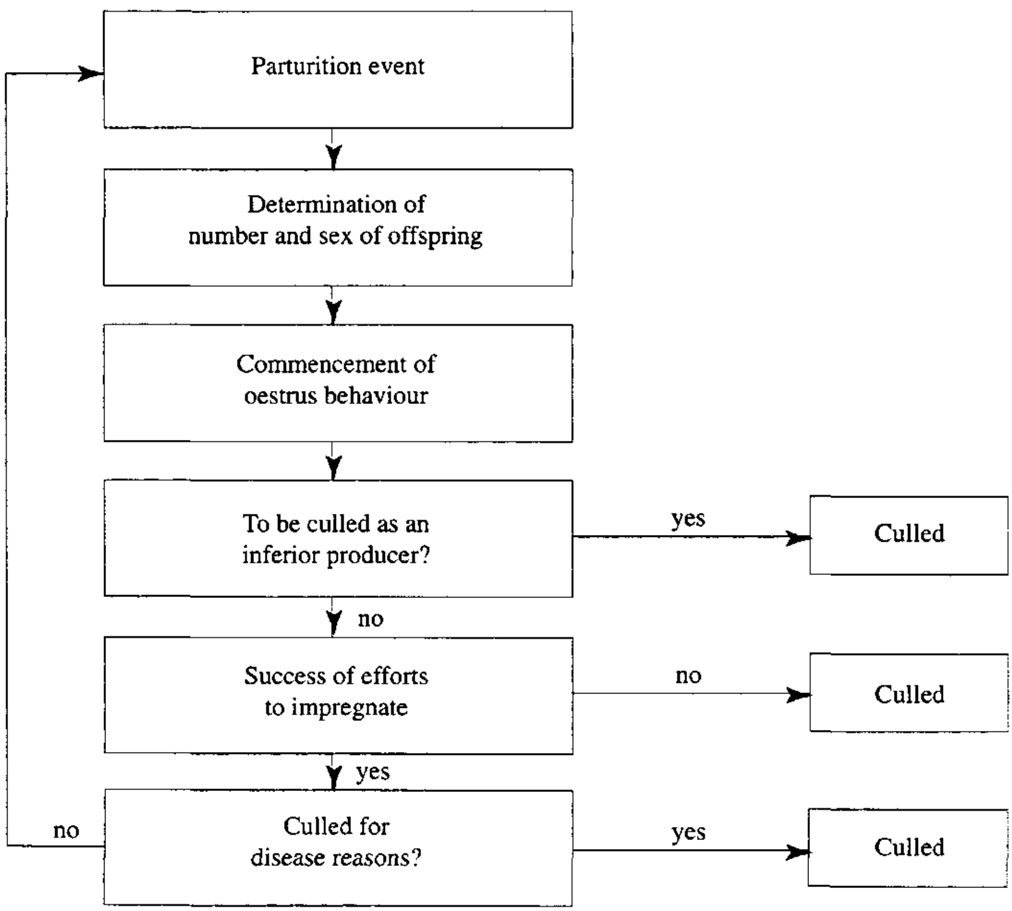

Figure 9.1 The generic livestock generator

birth, a female animal must first attain puberty, exhibit oestrus behaviour, mate, conceive, and complete gestation. Given this degree of commonality, it is apparent that if the core of a simulation model were structured around the reproductive cycle of the female animal, the generic livestock generator could be used as a starting point in modelling the reproductive cycles of a number of livestock species.

At any conception event a number equal to or less than some finite number of foetuses will be created. Between conception and parturition, not all of these potential offspring will survive: some or all may become resorbed, aborted or mummified. In the case of death or sale of the pregnant female, all the potential offspring will be lost to the herd. Consideration of these and other components of reproductive inefficiency, such as breeding-aged females failing to conceive or having extended intervals between parturition events, shows that livestock herds tend to produce far less viable offspring than is theoretically possible. Further losses are incurred through stillbirths, perinatal and pre-weaning mortality. The number of females available as replacements for the breeding herd is further reduced according to the sex ratio of the litter. Young stock mortality and removal of crossbred, diseased, slow-developing, and infertile females leave a reduced number of suitable females from which to select replacements for the breeding herd. Within any defined period, as long as the number of animals removed does not exceed the number of available replacement females, breeding herd size will be maintained. However, the more surplus replacements available, the greater the opportunity to replace genetically inferior animals with potentially superior replacements, or to increase the size of the production herd.

Should the removal (culling plus death) rate exceed the replacement rate, then not only will the herd size tend to decline, but also the opportunities for genetic selection in replace ment decisions will be foregone. Moreover, in order to maintain herd size at a constant level, the balance of the replacement females will have to be purchased from outside the herd, often with unknown genetic merit and/or disease status.

The generic livestock generator represents this dynamic process of maintaining a self-replacing production herd which is common to dairy, beef, sheep and pig herds on modern farms. The concept may be extended to other species kept as commercial enterprises such as rabbits, deer and fur-bearing mammals. The skeleton model presents the logical structure underlying the reproductive and productive processes of mammals, and only becomes functional when coupled with the species-specific parameters. These determine the scale and variability of such factors as oestrus behaviour, gestation length, litter size, timing of puberty, productive life span and marketable products.

The fundamental concept underlying the structure of the model is that the status of individual animals within a herd changes over time according to the probability of certain events taking place. The model 'moves' individual animals forward through time, modifying the status of each according to the outcome of stochastic decisions based on certain rules and probabilities. While there is one basic structural framework or skeleton model, the criteria for defining and the terminology used in describing status groups and events vary according to the species being modelled.

9.4.2 Individual animal simulation

Each production cycle for a mature female in the herd commences with a parturition event. A number of offspring are produced, the sex, number and survival of which are determined, based on long-term probabilities. At some time following the parturition event, oestrus activity commences, and attempts are usually made to get the mature female animal pregnant once more. If successful, the current production cycle is followed to its conclusion which coincides with the occurrence of the next parturition event, which becomes the starting point for the subsequent production cycle.

The only other events that can terminate a production cycle of a mature female are death or culling, signifying the departure of the female animal from the breeding herd. The occurrence of a culling event may be the outcome of reproductive failure, disease or a conscious decision by the herd manager to sell a surplus animal where a replacement of superior production potential is available. A culling event resulting from a disease condition can happen at any time within a production cycle, and efforts to impregnate a non-pregnant female may continue right up to the day of culling.

The fate of progeny born to mature females is determined in much the same manner except that some proportion of the female offspring are retained in the herd and reared as replacements for the breeding herd, while the remainder plus the unneeded males are eventually sold from the enterprise as marketable products. Thus the production cycle of an immature animal commences with a birth event and ends in a sale, culling or parturition event.

Life histories of mature male animals are not simulated individually because their number is typically proportionately very small when compared with the females in intensively-managed breeding herds. Instead, it is assumed that there is always adequate 'male power' available for purposes of reproductive activity, for which the enterprise is charged a monetary amount per service. This approach has the advantage that herds using natural service, artificial insemination, or a combination of both methods may be equally well represented by the modelling technique.

9.4.3 Whole herd simulation

After having developed the methodology for simulating production cycles for individuals, the process of how the life histories of many separate animals are combined to represent a model of a commercial breeding herd will be explained.

As described above, each production cycle for a mature female begins with a parturition event and terminates with death, culling or a subsequent parturition event. The simulation models presented in the next sections of this chapter are driven by an internal clock which has a base unit of one calendar day. As the clock advances each day, the record of each animal in the production or replacement herd is inspected for either a parturition or culling event which has previously been predicted to occur on that date. The clock will repeat this process for each day of the simulation period, which is typically set at one calendar year.

If a culling event is found, the animal is removed from the herd, the record deleted and the herd demographics adjusted accordingly. If the animal was sold for financial gain, a record of the sale is made. At the end of the simulation period, a sale price is randomly generated and included in the economic analysis section of the program.

If a parturition event is found, the simulation of the next production cycle for that animal is begun. The events which occur in the production cycle and their timing are determined stochastically by taking random observations on mathematically-defined frequency distributions. The shapes of these distributions are determined by the values of a number of management level variables which may be adjusted at the beginning of each time period being simulated. This sequence of events determines the status of each animal in the herd at any point in time, and provides the basic data necessary for the calculation of measures of reproductive performance for the breeding herd.

The first determination made after the parturition event is the number and sex of progeny born and the extent of perinatal mortality. Next, the first production cycle of surviving offspring is simulated to the point where each individual animal record contains a predicted date for a first parturition, or else for prior culling or death. In the case of immature males and excess immature females, there will be a predicted date of sale or death. Having dealt with the progeny, the model returns to the mature female and initiates her oestrus cycle, the timing and nature of which is species-specific.

If an oestrus is predicted, the time since parturition and the probability of oestrus behaviour being detected determines whether a service event takes place. Then, assuming a service event has taken place, the animal may or may not conceive depending on another random observation based on the long-term fertility levels set for the herd. If a conception is deemed to have taken place, then the next parturition date is forecast by adding the species' gestation length (plus or minus a random normal deviate) to the date of conception. If an abortion event is not predicted for this female then the simulation of reproductive activity ceases.

If an abortion event is predicted, and the time of abortion is within the permitted time frame for breeding activity, oestrus behaviour may be re-initiated, and attempts made to reimpregnate the animal. This is often the case for resorptions and early abortions. An abortion event late in pregnancy is usually immediately followed by a culling decision, except where the abortion would occur close enough to the forecast parturition date to be considered a premature birth. In the latter case, the event is treated as a premature parturition event, with appropriate effects on offspring viability and on the efficiency of production and reproduction in the subsequent production cycle.

Given the beginning and ending dates for the production cycle of each animal, and the pattern of reproductive events occurring during the intervening period, there now exists a framework upon which the estimation of the input-output relationships of the production processes can be made. In mammalian species, the useful output energy is characteristically in the form of products of the lactation and growth processes. Consideration of the efficiency level of these production processes and the relative price levels of energy inputs and outputs provides the basis for economic analyses.

Thus, the aggregation of the reproductive and productive activity of a group of animals provides a simulation model of a commercially-managed herd, from which projections of population dynamics, resource use, reproductive indices and economic analyses can be done.

9.5 DairyORACLE: a dairy herd simulation model

The model was developed as a tool for studying the effects of management decisions in dairy herds. As it is constructed around the skeleton model, it is particularly suited for studying the effects of various management strategies on the reproductive efficiency of a herd. Moreover, as the breeding herd must be maintained in a reasonably stable state to generate a constant income level, the ultimate effects of reproductive performance on population dynamics and financial performance are reported. Examples of uses of the model are comparisons of service windows, heat detection efficiencies, replacement heifer rearing strategies and various price levels for inputs and outputs.

In order that the computer can keep track of the population in the simulated herd, it keeps individual animal records which are similar in nature to those found in a computerized livestock production recording system. Each record is updated as events are predicted, and old information is discarded. Using this arrangement, the model is constantly aware of the status of each animal in the herd. The status of each animal changes with the passage of time and in light of the occurrence of simulated events. There are nine mutually exclusive and exhaustive status categories: maiden heifer; bred heifer; pregnant heifer; lactating cow, open; lactating cow, pregnant; low-producer, not to be served; dry cow; culled; and died.

9.5.1 Examples of functions used in the prediction of events

Calf sex and number

In the bovine, the most common litter size is one. Records of over two million births in dairy and beef cattle report the incidence of twins to be 1.04% or 1:96, of triplets 1:7500 and of quadruplets 1:700 000. Second, the average sex ratio of calves (male:female) was 51.12:48.88. Ignoring the possibility of triplets (a rare event) and quadruplets (a very rare event), this information is sufficient to construct a method for predicting litter size and sex ratio by taking a single random observation on a uniform distribution (with H = heifer and B = bull):

			frequency	cumulative
Single births:	H	0.4888 x 0.9896 =	0.4837164	0.4837164
	B	0.5112 x 0.9896 =	0.5058836	0.9896000
Twin births:	H H	0.2444 x 0.0104 =	0.0025418	0.9921418
	B B	0.2556 x 0.0104 =	0.0026582	0.9948000
	B H / H B	0.5000 x 0.0104 =	0.0052000	1.0000000

This method of computation is not strictly accurate because it assumes that single-sex and mixed-sex twin births occur in equal proportions. In reality, single-sex twins are more common because they may either originate from a single embryo which divided (monozygous) or from two separate embryos which were fertilized independently (dizygous). Mixed-sex twins can only be dizygous. However, as the incidence of twin births in cattle is low and with the absence of specific data on the sex ratio in twin births, the approximation is quite adequate for the purposes of this simulation model. On average, only one twin birth would be expected to occur each year in a 80-cow herd.

Thus, the generation of a random observation (x) will give the following results:

If $x \geq 0.0000000$ and $x \leq 0.4837164$:	single heifer calf
If $x > 0.4837164$ and $x \leq 0.9896000$:	single bull calf
If $x > 0.9896000$ and $x \leq 0.9921418$:	twin heifer calves
If $x > 0.9921418$ and $x \leq 0.9948000$:	twin bull calves
If $x > 0.9948000$ and $x \leq 1.0000000$:	mixed twins

A further assumption made is that only the single and twin heifer births produce suitable offspring for rearing as replacements. All bull calves and heifer calves from mixed-sex births are sold, as there would be a chance that those in the latter group would be freemartins. This policy is commonly practised on dairy farms.

Calf record

If a heifer calf survives to weaning at approximately 6 to 8 weeks of age, the model proceeds to simulate her lifetime events up to the date of first calving, sale or death.

First the heifer is assigned an identity. Identities are typically the next highest number in a consecutive sequence, such that the youngest animal in the herd carries the highest number. Once assigned, identities are retained for life, and are never re-assigned within a simulation run. These 'cow numbers' are printed on the lactation simulation display screen to assure the user that the model actually simulates the life-time events of individual animals.

A heifer may die before reaching maturity: a random observation on a uniform distribution is taken. If the observation is less than or equal to the yearly mortality level specified, then the heifer is judged to have died. The actual time of death is determined by taking a second random observation on a normal distribution with a mean of 360 days and a standard deviation of 100 days. Thus the death event may occur at any time between 2 months and 22 months of age, normally distributed around 12 months of age.

Next, the date at which the heifer will conceive is determined. The gamma distribution is used for this prediction as it is particularly suitable for simulating time-delayed events on a continuous random variable (Payne, 1982). A single parameter, lambda, is supplied to the distribution representing the average number of days from the minimum breeding age to conception. A convenient method for estimating lambda is:

$$\text{LAMBDA} = (\text{IEI} / 2.0) + (\text{IEI} \times \text{SRV})$$

where

IEI = average inter-oestral interval (days); and

SRV = number of services per conception.

For example, an IEI of 21 and a SRV of 1.9 would yield:

$$\text{LAMBDA} = (21 / 2.0) + (21 \times 1.9) = 50.4 \text{ days.}$$

The first part of the expression allows for the fact that, on average, there will be a delay of one-half of an inter-oestral period between a heifer attaining minimum breeding age and being served for the first time.

Once the conception date has been determined, the projected date of calving is determined by the equation:

$$\text{DUEDATE} = \text{CONDATE} + \text{GESTCOW} + \text{RANDNORM}(0.0, 3.0)$$

where

DUEDATE = date due to calve;
CONDATE = simulated conception date;
GESTCOW = average gestation length for the species; and
RANDNORM(0.0, 3.0)
= a random observation on a normal distribution with a mean of 0.0 and a standard deviation of 3.0 days.

Thus, for a GESTCOW value of 283 days, 99.9% of the gestation periods will fall in the range of 274 to 292 days, normally distributed around a mean of 283 days.

In any group of replacement heifers, there will always be a certain proportion of animals which fail to conceive, and sold as cull animals. The use of the gamma distribution for the prediction of conception dates in heifers provides a convenient method of simulating this situation. A variable, BARREN, indicates the age at which any non-pregnant heifer is considered to be a non-breeder. If the age of the heifer at the predicted conception date exceeds the value of BARREN, then the model discards the conception event, and the animal is sold.

Milk production

The equations used to generate lactation curves are adapted from those developed by Oltenacu *et al.* (1981). Daily milk yield of a cow as a function of her days in milk is predicted by:

$$Y = \text{GEN}(\text{DIM})^{b}\, e^{c\text{DIM}(\text{DP}+1)}$$

where

Y = daily milk yield (kg);
GEN = genotypic production potential;
DIM = day of lactation (days in milk);
DP = number of days pregnant; and
e = the base of the natural logarithm.

Separate lactation curves are generated for lactation 1, lactation 2 and mature cows. This is affected by supplying different values for parameters b, c, d, g in each case.

The genotypic production potential for each cow in the starting herd is assigned at the beginning of each simulation run by taking the integer value of a random observation on a normal distribution with a mean of 100 and standard deviation of 10 - RANDNORM(100.0, 10.0), to give a range of 70 to 130. Heifer calves 'born' within the model are assigned their production potential values at birth.

The lactation milk production is derived by integrating the area under the curve between the calving date and the drying-off or culling date for each cow. A variable CRITICAL is the daily milk yield below which the user does not consider it worthwhile milking a cow. Should the daily milk production fall below the level of CRITICAL, then the model will prematurely dry off a cow to begin an extended dry period. This situation is typically found where a low-yielding cow has an extended lactation following a delayed conception.

In the case of cows that do not become pregnant and are not culled for disease reasons during a lactation, a modified algorithm is used. The culling date is determined by the shape of the lactation curve, with the cow being retained in the herd and milked until her daily milk production falls below CRITICAL. This is the mechanism by which cows that fail to conceive 'fall out' of the model.

While the current version of the model uses the above formula for generating lactation curves, it is important to remind the reader that it was developed from Dairy Herd Improvement Association records for herds in New York State (Oltenacu *et al.*, 1981), and it may not be appropriate for applications of the model in other parts of the world. Characteristically, feeding programs in dairy production systems in the northern United States involve moderate to heavy levels of grain combined with forage provided as conserved corn (maize) silage and alfalfa hay or silage. The result is a high-protein, high-energy diet with little seasonal variation.

In parts of the world where dairy herds are grazed for their forage supply and production is geared to seasonal patterns of forage growth and quality, it may be more applicable to use other lactation curve equations, such as those by workers of the Milk Marketing Board in England and Wales. The model: $y = A\ n^b\ e^{-cn}$, developed by Wood (1967) was the first to attempt to describe an entire lactation. The equation expresses average daily milk yield (y) in the n^{th} week of lactation, where A, b, c are positive parameters that determine the shape of the curve. Wood applied this model in a number of later studies of lactation curves in British Friesian cattle taking into account season of calving and the 'spring hump' where milk production is stimulated by the change in diet of conserved forage to fresh grass.

Cobby and Le Du (1978) expanded the model of Wood (1967), and more recently, Van Arendonk (1985) extended the model of Cobby and Le Du to include the effect of season of milk production and days open:

$$Y_{t_l,\ i,\ DO} = (a - bt_l - 13e^{-ct_l})(1 + (t_p/140)^2)^{-1} f_m g_i$$

where

$Y_{t_l,\ i,\ DO}$ = the milk production (kg) at t_l days after calving for the i^{th} month of calving and DO days open;

a	= level parameter (kg);
b	= the slope during the decline in production after the peak production (kg per day);
c	= parameter describing the initial increase in production;
t_p	= t_l - DO - 122 when t_l > DO + 122 and t_p = 0 when t_l < DO + 122;
f_m	= effect of the m^{th} calendar month of the year on monthly production; and
g_i	= effect of the i^{th} month after calving on the level of production.

It is thought appropriate that a suite of lactation curve algorithms be provided for applications of the model outside of the United States, particularly for developing countries and areas where the system of milk production is low-input / low-output in nature.

9.5.2 Model output

As individual animal records are used in the simulation procedures, there are a tremendous number of data produced in the course of one simulated year. In order that the performance of the herd be evaluated and compared among different simulated scenarios, the data must be distilled down to a comparatively few, but meaningful, reports. Once again the modeller is faced with a dilemma of deciding what to report, and in what form to present it. Report categories are: population demographics; performance indices; reproductive performance; monthly graphics; livestock valuation; cash flow analysis; and income statement. Two of these will now further be illustrated.

Table 9.1 DairyORACLE reproductive performance indices report

	Reproductive performance indices					
	year 1	**year 2**	**year 3**	**year 4**	**year 5**	**year 6**
Calving to first service						
Median interval (d)	83	85	84	81	85	83
Mean interval (d)	90.2	85.4	84.9	83.8	90.9	82.6
% cows re-served	81.0	86.2	87.9	83.0	92.5	84.9
Calving to conception						
Median interval(d)	143	135	114	129	114	182
Mean interval (d)	103.3	113.5	100.7	99.0	108.4	110.3
% cows re-conceiving	60.3	67.7	65.5	69.8	79.2	60.4
Summary measures						
Heat detection eff. (%)	38.7	42.9	40.0	45.2	44.3	35.9
1st service preg. rate (%)	42.6	41.1	47.1	52.3	55.1	44.4
Services per conception	1.5	1.8	1.5	1.5	1.6	1.5
Service: conception ratio	2.2	2.4	2.1	2.1	2.0	2.4
Annual replacement rate (%)	33.3	25.6	29.5	35.2	30.1	33.5
Calf mortality (%)	2.2	8.1	7.7	0	4.2	4.5

Performance indices

The performance indices fill two video display screens or one sheet of paper. The first screen is mainly concerned with reproductive performance, while the second contains a mixture of physical and financial measures. This report accumulates figures for six years of simulated data, making it convenient to compare results between years and to follow trends. The cohort used for the reproductive indices is the group of cows calving in the year simulated, and thus is directly comparable with the DairyCHAMP annual report. The physical and financial measures relate to events occurring within the simulated period.

Note that although model inputs such as heat detection efficiency and first service pregnancy rates were held constant throughout the 6-year period simulated in this example, the values shown in the annual summary values appear to fluctuate from year to year. This phenomenon is to be expected, as the simulation model is properly mimicking the natural biological variation that occurs in such animal populations.

Financial statements

The DairyORACLE model provides both cash flow and income statements for the dairy enterprise. The income statement retains data for all six simulated years, and enables trends to be seen at a glance. The four main financial categories featured in this report are total cash inflow, variable expenses, fixed expenses and income tax treatment.

Total cash inflows include the four categories of off-farm sales, which are: milk; calves; cull cows, and surplus springing heifers.

Variable expenses include all expenses which vary with the number of cows in the herd or the level of production: forage expense, dairy grain, heifer grain, calf milk replacer, labour expense, springing heifer purchases, breeding fees, veterinary and medical expenses, utilities and fuel, and chemicals and supplies.

Fixed expenses are those expenses which do not vary directly with a marginal change in the number of cows in the herd or the level of production. However, it should be noted that an appreciable change in the magnitude of the enterprise or production level will necessitate an adjustment of items in this category: interest on long-term debt, insurance premiums, and repairs and maintenance to buildings and equipment.

The cash flow statement is computed for twelve monthly periods for each simulated year. Due to the size limitations of the video display terminal, results are summarized for four quarterly periods. A fifth column displays annual totals.

The bottom part of the statement is the cash flow resolution calculations. The model will not permit the cash balance to fall below zero, but will automatically borrow from a line of credit sufficient funds to preserve a positive or zero balance. Interest on this loan is assessed on a monthly basis. When a positive cash flow permits the repayment of operating loans, interest is always paid before principal. All such interest payments are deducted from the taxable income in the income statement.

Table 9.2 DairyORACLE financial statement report

	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5
Milk sales income	126,496	130,651	142,774	128,753	136,199
Calf sales income	4,630	4,183	4,697	4,320	5,067
Cull sales income	9,817	6,657	8,234	13,647	13,791
Springing heifer sales	0	0	0	0	0
TOTAL CASH INCOME	140,943	141,491	155,705	146,720	155,057
Forage expense	30,165	31,966	34,882	31,097	33,629
Dairy concentrates	21,054	21,572	23,584	21,345	22,423
Heifer concentrates	10,325	10,022	11,425	13,432	14,091
Calf milk replacer	687	701	652	734	800
Labour expense	10,313	10,928	11,926	10,632	11,497
Springing heifers bought	0	0	0	0	0
Breeding fees	1,310	1,610	1,370	1,340	1,300
Veterinary & medical	3,826	3,335	4,445	3,626	4,123
Utilities & fuel	11,998	11,975	11,989	13,125	12,463
Chemicals & supplies	4,004	3,992	4,375	4,154	4,416
TOTAL VARIABLE EXPENSES	93,682	96,101	104,648	99,485	104,742
ENTERPRISE GROSS MARGIN	47,261	45,390	51,057	47,235	50,315
Payments on long-term debt	9,300	9,300	9,300	9,300	9,300
Insurance premiums	1,500	1,500	1,500	1,500	1,500
Repairs & maintenance	2,500	2,500	2,500	2,500	2,500
TOTAL FIXED EXPENSES	13,300	13,300	13,300	13,300	13,300
TOTAL CASH INFLOWS	140,943	141,491	155,705	146,720	155,057
TOTAL CASH OUTFLOWS	106,982	109,401	117,948	112,785	118,042
NET CASH FLOW BEFORE TAX	33,961	32,090	37,757	33,935	37,015
Change in herd valuation	12,525	12,525	12,525	12,525	12,525
NET INCOME BEFORE TAX	46,486	44,615	50,282	46,460	49,540
Interest on operating loan	0	0	0	0	0
TAXABLE INCOME	46,486	44,615	50,282	46,460	49,540
Income tax due	20,268	19,314	28,099	20,255	21,826
AFTER TAX NET INCOME	26,218	25,301	22,183	26,205	27,714
AFTER TAX NET CASH INCOME	13,693	12,776	9,658	13,680	15,189

9.6 PigORACLE: a pig herd simulation model

The nine mutually exclusive and exhaustive status categories for animals simulated within PigORACLE are: gilt, selected for and entered breeding herd; gilt, served; gilt, diagnosed pregnant; sow, lactating; sow, weaned; sow, served; sow, served before weaning; sow, diagnosed pregnant; and sow, diagnosed not pregnant. The nomenclature of the status groups reflects the fundamental processes in the reproductive biology of the porcine species.

9.6.1 Examples of functions used in the prediction of events

Litter size and number

Mean total litter size in sows increases to peak around the fourth, fifth, sixth and seventh parities, and declines thereafter. The decline in older sows is attributable to an increase in embryonic death rate. Because of this relationship between parity and litter size, the

PigORACLE input screen dealing with breeding herd management allows the user to edit the values for expected average litter sizes by age: from first parity gilts up to seventh parity and older sows. As the distribution of litter sizes is approximately normal, a random observation on a normal distribution is made to generate an integer which represents the total number of pigs born in an individual litter. Experimentation with the random generation process has shown that for mean litter sizes between 7 and 15, a standard deviation equal to one-fourth of the mean gives a satisfactorily realistic spread of total litter sizes.

Use of the random number generation process involves a very small chance that a litter size greater than that which has been observed in nature being generated. Therefore, a constant, (MAXLITTER) is used to truncate the distribution, such that if a litter size greater than MAXLITTER is predicted, the model will 'throw away' the observation and generate a new one. MAXLITTER is currently set at 25, but can be changed if larger total litter sizes are observed in swine herds.

Culling and removal

Analysis of the PigCHAMP culling data has shown a peak in the frequency of culling events at around 5 weeks post-farrowing, which coincides with the completion of the lactation period. In order to generate probability distributions for the timing of removal, the reasons for removal have been broken down into four categories which correspond to the coding system used by PigCHAMP:

- lameness, injuries, and degenerative problems;
- specific systemic diseases;
- miscellaneous problems;
- reproductive problems: farrowing and litter-related; and
- reproductive problems: fertility-related.

Sows with fertility-related problems 'fall out' of the model as a consequence of failing to conceive or to complete a gestation successfully, and therefore do not require any additional mechanism for timing their removal. The time of removal for each culled sow is predicted by taking a random observation on a Poisson distribution. However, in this case the value returned is the number of weeks postpartum rather than months. A random observation on a uniform distribution returns an integer between 1 and 7 which represents the day of the week when the culling is predicted to take place.

Weaning to first oestrus intervals

The process involved in the prediction of oestrus events is based on the lognormal distribu tion. The first oestrus in sows normally occurs shortly after the completion of the lactation period, the average weaning to oestrus interval being 4 - 5 days. Default values of a mean of 7 days with a standard deviation of 1 day gives a distribution with 90% of sows in heat by 8 days post-weaning. The measured mean and standard deviation of this distributions are 5.7 and 1.36 respectively. A mean of 21 days and a standard deviation of 1.5 days are used as default values for the inter-oestral interval.

9.6.2 Model output

Although PigORACLE has many built-in reports (similar to DairyORACLE), both models can generate batch input files for PigCHAMP and DairyCHAMP respectively. Once model output has been saved as a PigCHAMP data file, all PigCHAMP reports and options may be used to analyse and present simulated data. Biological performance of a start-up herd is shown by the Performance Monitor Report (Table 9.3). Changing patterns in breeding, farrowing and weaning performance can be observed as the herd develops from a flow of purchased gilts to a mature parity distribution over the 5-year simulation period.

Table 9.3 Simulated data from PigORACLE in PigCHAMP Performance Monitor Report

PERFORMANCE MONITOR — PigCHAMP 3.05
1 JAN 88 - 31 DEC 93 — (C) 1985,87,88,91 Univ of Minn
FARM: WEANWEDS — Licensed to William E. Marsh
Printed: 31 DEC 93

	JAN 88 DEC 88	JAN 89 DEC 89	JAN 90 DEC 90	JAN 91 DEC 91	JAN 92 DEC 92	JAN 93 DEC 93	JAN 88 DEC 93
BREEDING PERFORMANCE							
Total number of services	645	599	632	620	612	669	3777
Percentage repeat services	11.3	10.5	9.8	9.5	9.3	12.1	10.5
Weaning - 1st service interval	5.4	6.1	5.7	5.5	5.1	5.4	5.5
Percentage sows bred by 7 days	87.9	83.2	85.7	86.2	90.9	87.3	86.8
Entry - 1st service interval	5.6	4.9	6.0	5.8	5.3	6.0	5.6
FARROWING PERFORMANCE							
Number of sows farrowed	376	516	532	532	526	554	3036
Ave parity of sows farrowed	1.4	2.9	4.1	4.8	5.6	6.0	4.3
Average total pigs per litter	10.3	11.1	11.2	11.2	11.2	11.3	11.1
Average pigs born alive/litter	9.3	10.1	10.1	10.0	10.0	10.0	10.0
Percentage stillborn pigs	9.5	9.2	9.9	10.7	10.3	10.9	10.1
Farrowing rate	84.7	84.2	86.1	85.1	84.8	86.3	85.2
Adj. farrowing rate	87.9	88.4	89.7	89.0	88.7	89.2	88.8
Farrowing interval	143	145	144	144	144	144	144
Litters / mated female / year	2.57	2.43	2.48	2.46	2.48	2.46	2.48
Litters / crate / year	9.4	12.9	13.3	13.3	13.1	13.9	12.6
WEANING PERFORMANCE							
Number of litters weaned	345	516	535	531	530	542	2999
Total pigs weaned	2766	4454	4644	4611	4611	4616	25702
Pigs weaned per sow	8.0	8.6	8.7	8.7	8.7	8.5	8.6
Preweaning mortality	14.1	14.3	13.6	13.7	13.4	14.8	14.0
Average age at weaning	21.9	21.7	21.7	21.7	21.6	21.5	21.7
Pigs wnd/mated female/yr	20.6	21.0	21.5	21.4	21.5	21.0	21.2
Pigs weaned/crate/year	69.0	111.3	116.1	115.3	115.0	115.4	107.0
Pigs weaned/lifetime female	6	20	32	39	49	47	33
POPULATION							
Ending female inventory	222	215	213	208	226	244	244
Average parity	1.5	2.7	3.7	4.5	4.9	5.1	5.1
Average female inventory	184.1	211.3	217.4	218.2	216.6	223.9	211.9
AFI / Crate	4.6	5.3	5.4	5.5	5.4	5.6	5.3
Average gilt pool inventory	4.1	1.2	1.4	1.2	1.2	1.6	1.8
Gilts entered	269	87	84	76	85	95	696
Sows and gilts culled	43	90	82	74	59	70	418
Sow and gilt deaths	2	2	1	5	3	2	15
Replacement rate	145.7	41.2	38.6	34.8	39.1	42.4	54.7
Culling rate	23.3	42.6	37.7	33.9	27.2	31.3	32.8
Death rate	1.1	0.9	0.5	2.3	1.4	0.9	1.2
Ave non-productive sow days	33.2	33.7	28.6	30.8	29.4	31.0	31.0
Ave NPD / parity record	9.5	11.8	10.1	11.1	10.4	10.7	10.6

Although all input values were held constant for the duration of this run, the values of such measures as percentage of repeat services, farrowing rate, and preweaning mortality fluctuate from year to year. This is an artifact of the stochastic simulation process. As these measures naturally fluctuate, reflecting variability in the underlying biological processes, stochastic simulation models can be helpful in setting production targets and interference levels. **Multiple simulation runs** can provide the data from which to calculate long-run averages, and provide a statistical basis for identifying significant deviations, quantified in standard deviations from the mean.

Monte Carlo simulation models are most useful when the aggregate results of multiple runs are pooled to provide estimates of expected values and associated variability. In fact, potential users should be warned of the dangers of interpreting the results of a single run of the model, as it may, by chance, reflect a particularly favourable or unfavourable set of outcomes, which may be unlikely to be encountered in the real world. We recommend that the results of a set of a minimum of ten replications of PigORACLE simulations be interpreted as a set, as the model runs very quickly on state-of-the-art personal computers.

9.7 Concluding remarks

The concept of developing a generic model of reproduction and production in breeding livestock herds using Monte Carlo simulation techniques has been illustrated to the point that functional models of dairy and swine enterprises have been constructed from a common skeleton model of reproductive behaviour. The models provide satisfactory approximations to the biology of reproduction in dairy and swine herds, and provide the means to quantify performance in economic terms (eg, Marsh, 1986; Marsh *et al.*, 1987). Experience in building, testing and applying these models has shown that, due to the many complex relationships that exist within breeding livestock herds, quite subtle changes in management policy can have far-reaching effects on the demographics, productivity and profitability of the enterprise. Comparison of replicate runs of the program (using different random number seeds) serves to illustrate how the inherent natural variability of livestock production systems can often lead to surprising results, even when management policies are followed faithfully.

References

Anderson, J.R., 1974. Simulation: methodology and application in agricultural economics. Review of Marketing and Agricultural Economics 43: 3-55.

Blackie, M.J. & Dent, J.B., 1974. The concept and application of skeleton models in farm business analysis and planning. Journal of Agricultural Economics 25: 165-173.

Cobby, J.M. & Le Du, Y.L., 1978. On fitting curves to lactation data. Journal of Animal Production 26: 127-133.

Marsh, W.E., 1986. Economic decision making on health and management in livestock herds: examining complex problems through computer simulation. PhD-thesis, University of Minnesota, St. Paul, 304 pp.

Marsh, W.E., Dijkhuizen, A.A. & Morris, R.S., 1987. An economic comparison of four culling decision rules for reproductive failure in U.S. dairy herds, using DairyORACLE. Journal of Dairy Science 70: 1274-1280.

Morris, R.S., 1976. The use of computer modelling in epidemiological and economic studies of animal disease. PhD-thesis, University of Reading, 479 pp.

Oltenacu, P.A., Rounsaville, T.R., Milligan, R.A. & Foote, R.H., 1981. Systems analysis for designing reproductive management programs to increase production and profit in dairy herds. Journal of Dairy Science 64: 2096-2104.

Payne, J.A., 1982. Introduction to simulation: programming techniques and methods of analysis. McGraw-Hill, 324 pp.

Shannon, R.E., 1975. Systems simulation: the art and science. Prentice-Hall, Inc. Englewood Cliffs, NJ, 387 pp.

Van Arendonk, J.A.M., 1985. A model to estimate the performance, revenues, and costs of dairy cows under different production and price situations. Agricultural Systems 16: 157-189.

Wood, P.D., 1967. An algebraic model of the lactation curve in cattle. Nature 216: 164-165.

10

Scope and concepts of risky decision making

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Objectives

From this chapter the reader should gain knowledge of:

- the basic steps in the decision-making process
- the concepts of decision theory, taking into account the risk attitude of the decision maker(s)
- the various choice criteria, such as expected utility model, stochastic efficiency criteria and expected monetary value
- Bayes' theorem and the economic value of information

10.1 Introduction

The economic success of animal health management is closely related to the way in which decisions are taken and implemented. The decision-making process is essentially a five-step procedure:

1. defining the problem or opportunity;
2. identifying alternative courses of action;
3. gathering information and analyse each of the alternative actions;
4. making the decision and take action; and
5. evaluating the outcome.

The first step is probably the most important one. When problems are not recognized, continuing losses may occur, particularly with subclinical diseases and reduced fertility. Monitoring systems especially within herd health programs are increasingly used to register, and to help identify, these problems. Once a problem has been defined, it will seldom be the case that there are no reasonable solutions or actions to be taken (step 2). It will be more common that the number of alternatives has to be limited, so that each can be examined thoroughly. For documenting and examining the potential effects of the various alternative actions (step 3), it will not be feasible to have only actual field data available. Computer simulation has long been recognized as a complementary approach and is particularly attractive when real-life experimentation would be impossible, costly or disruptive.

Whichever way, and to whatever extent, the information has been provided, the fourth step is always taken, either consciously (by choosing the 'best' option) or not (which implicitly means a continuation of the available strategy). Evaluating the outcome of actions taken (step 5) brings the decision maker back to the first step, thus making the process a **cyclical** one.

Decision making in animal health management has to deal with several factors over which the decision maker has little or no control, making the outcome of actions uncertain. Different criteria can be applied to what is called 'decision making under risk'. Some of those criteria are discussed below and illustrated with an example.

10.2 Components of a risky decision problem

Traditional analyses of decision making have distinguished two types of imperfect knowledge: **risk**, when the probabilities of the uncertain outcomes are known, and **uncertainty**, when they are not. However, this distinction is of little practical use and is discarded by most analysts today. Probabilities can be 'known' only for the so-called stationary stochastic processes, ie, for events where there is variability but where the sources and nature of the variability remain constant through time. Such processes are rare in practical decision making. In modern discussions and analyses, therefore, the terms risk and uncertainty are used more or less interchangeably.

Any **risky decision** involves five components: acts, states, probabilities, consequences and a choice criterion (Anderson *et al.*, 1977). **Acts** (a_j) are the relevant actions available to the decision maker. They constitute the relevant set of mutually exclusive alternatives among which a choice has to be made. Examples of acts in animal health management are 'treat' or 'do not treat' an animal, or 'keep' or 'replace' a specific animal. The possible events or **states of nature** (θ_i) must also be defined by a mutually exclusive and exhaustive listing. Examples of states of nature are 'good', 'average' or 'poor' rainfall, or 'severe', 'normal', 'small' or 'no' outbreaks of a certain disease. The essence of a risky decision problem is that the decision maker does not know for certain which state will prevail. Some state variables are intrinsically continuous (eg, herd health status), but generally a discrete representation (such as good, average or bad) will prove adequate. **Prior probabilities** (P_i) reflect the degrees of belief held by the decision maker about the chance of occurrence of each of the possible states. Such probabilities are considered subjective or personal in nature. Example probabilities for a disease problem can be as follows: a probability of 0.2 for a 'severe' outbreak, 0.3 for a 'normal', 0.25 for a 'small' and 0.25 for 'no' outbreak of a certain disease. Depending on which of the uncertain states occurs, choice of an act leads to some particular **consequence**, **outcome** or **payoff**. Finally, some **criterion of choice** is necessary to compare the possible consequences of any act with those of any other act. One such criterion is the expected monetary value (EMV), defined as the summation of the possible money outcomes multiplied by their probabilities.

Consider a simplified case in which a farmer can choose between two acts, ie, herd health programs a_1 and a_2. The payoffs of the programs are expected to differ according to the actual health status of the herd. These 'states of nature' can be good, average or bad, with an estimated (subjective) probability of 0.2, 0.6, and 0.2 respectively. Results are summarized in Table 10.1.

Table 10.1 Payoff matrix for two herd health programs (US$)

States of nature (θ_i)	P(θ_i)	Program a_1	Program a_2
Herd health good (θ_1)	0.2	1000	-10000
Herd health ave. (θ_2)	0.6	4000	5000
Herd health bad (θ_3)	0.2	9000	19000
Expected monetary value		4400	4800

When taking into account the mean outcome (ie, expected monetary value) to compare the alternatives, program a_2 is the preferred one. This choice, however, does not hold for the situation should the herd health status be good, thus making this a classical example of risky choice.

10.3 Subjective expected utility model

One of the most widely applied models for studying decision making under risk is the subjective expected utility (SEU) model (Anderson *et al.*, 1977). Using the model, actions are ordered according to the beliefs and risk attitudes of the decision maker. Each outcome is assigned a utility value (ie, preference), according to a personalized, arbitrarily scaled **utility function.** The utility values for each possible outcome of an action are weighed by their (subjective) probability and summed across outcomes. The resulting expected utility is a preference index for that action. Actions are ranked according to their levels of expected utility with the highest value being preferred. Farmers' attitudes towards risk vary depending on their objectives and financial resources, for instance. Most farmers, like other people, tend to be risk averse.

Suppose that a farmer's utility function for gains and losses is adequately represented by:

$$U(x) = x - 0.005x^2 \quad \text{for } x \leq 50$$

where x denotes thousands of US dollars.

This function makes it possible to convert the money values for each of the alternatives in Table 10.1 to utility values (U):

$$\begin{aligned} U(a_1) &= 0.2U(\text{US\$1000}) + 0.6U(\text{US\$4000}) + 0.2U(\text{US\$9000}) \\ &= 0.2(0.995) + 0.6(3.920) + 0.2(8.595) = 4.270 \end{aligned}$$

$$\begin{aligned} U(a_2) &= 0.2U(\text{US\$ -10 000}) + 0.6U(\text{US\$5000}) + 0.2U(\text{US\$19 000}) \\ &= 0.2(-10.5) + 0.6(4.875) + 0.2(17.195) = 4.264 \end{aligned}$$

So, taking into account the risk-averse attitude of the farmer makes program a_1 the preferred one, ie, yielding the highest subjective expected utility.

The implementation of the SEU model requires the risk preferences of decision makers (ie, the utility function) to be known. The notion of certainty equivalent is central to the measurement of these preferences, and hence to the elicitation of the utility function. When given a choice between (a) payment of US$1000 for sure versus (b) a chance of winning US$5000 with a probability of 0.25, for instance, most people will opt for (a), even though (b) has a higher expected monetary value. The **certainty equivalent** (CE) of a risky prospect then is the value which the decision maker is just willing to accept in lieu of the risky prospect. So, the relationship between the CE and the expected monetary value (EMV) of the outcomes tells something about the decision maker's attitude towards risk. If the person is averse to risk, which is normally the case, (s)he will assign a CE less than EMV. For people that have a preference for risk CE will be greater than EMV, while in the case of risk indifference CE = EMV.

Methods of eliciting utility functions involve asking people to specify their CEs for specified risky prospects. According to Anderson *et al.* (1977), the simplest recommended method is based on considering an Equally Likely risky prospect and finding its Certainty Equivalent. In using this so-called **ELCE-method,** the first step is to find the CE for a hypothetical 50/50 lottery with the best and worst possible outcomes of the decision problem as the two risky consequences. The next step is to find the CE for each of the two 50/50 lotteries involving the first-established CE and the best and worst possible outcomes. This process of establishing utility points is continued until sufficient CEs are elicited to plot the utility function. In order to obtain meaningful values it is important to provide enough realism for this type of game setting (Smidts, 1990). Moreover, worthwhile outcomes require utility functions to be described in a mathematically sound way, thus making the choice of the function form very important.

10.4 Other choice criteria

Utility functions may not always be easy to elicit. Many authors, therefore, have suggested alternative rules that might be used, leaving it to the individual decision maker to decide what criterion is the most appropriate given his/her own specific situation (Barry, 1984).

A first group of criteria includes those that do not require probability estimates:

- **Maximin** is a criterion that arises from a very pessimistic or conservative risk attitude. Each action is judged solely on its worst outcome, and the one that maximizes the minimum gain is selected. In the example of Table 10.1 the minimum gains of the two programs are US$1000 and -10 000 respectively, with program a_1 being the preferred one according to this criterion.
- **Minimax** regret is similar to the previous criterion but it argues that the 'correctness' of a decision be measured by the amount by which the outcome could have been increased, had the decision maker known some information beforehand, and then selects the action with the smallest maximum increase (ie, regret). This is a criterion which has in mind judgment by hindsight. When choosing program a_2 in Table 10.1 the maximum possible

regret is US$11 000 (ie, US$1000 - (-10 000), in case herd health turned out to be good), while with program a1, this is US$10 000 (ie, US$19 000 - 9000, if herd health was bad). So, program a1 is now the preferred one.

- **Maximax** simply amounts to scanning the outcome matrix to find its largest value and then taking the corresponding action. This is a totally optimistic criterion, and similar to the approach of a gambler. In Table 10.1 this would result in program a_2 being taken (ie, US$19 000 being the largest payoff).

A second group of criteria includes more than one single value of the outcome distribution and, therefore, do require probability estimates:

- **Hurwicz α index rule** allows for a weighed average of the minimum and maximum outcome per action, and then selects the action with the highest weighed average. In formula:

$$\text{Max } [I_j = \alpha(M_j) + (1\text{-}\alpha)(m_j)]$$

where α is supplied by the decision maker subject to $0<\alpha<1$, M_j equals the maximum gain of action j, and m_j equals the minimum gain of action j. Should $\alpha = 0.5$, then the outcome in Table 10.1 is 0.5 x 9000 + (1-0.5) x 1000 = US$5000 for program a_1 and 0.5 x 19 000 + (1-0.5) x -10 000 = US$4500 for program a_2. Program a_1 then is preferred.

- **Laplace principle of insufficient reason** selects the action with the highest expected outcome, based on equal probabilities for all outcomes. Unlike the previous criteria it takes into account the outcomes for all events, but still ignores that one event may be (considered) more likely than the other. For the example in Table 10.1 this turns out to provide an equal outcome for the two programs, ie, (1000 + 4000 + 9000)/3 = US$4667 for program a_1 and (-10 000 + 5000 + 19 000)/3 = US$4667 for program a_2.
- **Expected Monetary Value** is probably the best-known criterion, and is defined as the summation of the possible levels of outcome multiplied by their probabilities. If there are m possible states for the j th action with the i th state denoted θ_i, having outcome O_{ij} and probability P_i, then the expected monetary value of the outcome is given by:

$$EMV(O_j) = P_1O_{1j} + P_2O_{2j} + ... + P_mO_{mj} = \Sigma P_iO_{ij}$$

It assumes that the decision maker's satisfaction is measured by the level of profit, which in fact is a special linear case of the more general expected utility model (ie, assuming risk neutrality of the decision maker). The outcome for the two programs in the example was already given in Table 10.1, with program a_2 being the preferred one in this case.

None of the previous criteria, however, takes account of any 'utility-based' trade-off between the average outcome of each strategy and its variance. That is why **stochastic efficiency criteria** (the third group to be considered) are proposed as a useful alternative, at least for cases where probabilities are reasonably well defined. Stochastic efficiency rules satisfy the axioms of the expected utility model but do not require precise measurement of risk preferences. However, as opposed to the complete ordering achieved when risk preferences are known, they provide only a partial ordering (King & Robison, 1984). Stochastic efficiency rules are implemented by pairwise comparisons of cumulative distribution functions of outcomes (y) resulting from different actions.

- **First-degree stochastic dominance (FSD)** holds for all decision makers who prefer more to less (ie, whose first derivative of the utility function is positive). No assumptions are made about risk preferences of the decision maker, which widens the possibilities of application but limits its discriminatory power. Graphically, these conditions mean that the cumulative of the dominant (ie, preferred) distribution must never lie above the cumulative of the dominated distribution. In Figure 10.1, for example, F(y) dominates G(y) by FSD, but neither F(y) nor G(y) can be ordered by H(y).

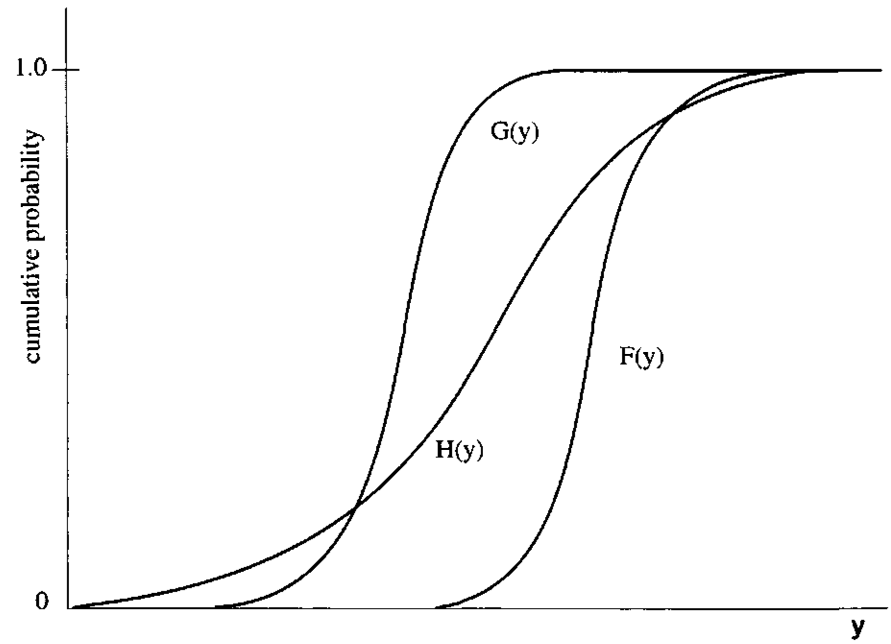

Figure 10.1 First- and second-degree stochastic dominance

- **Second-degree stochastic dominance (SSD)** assumes that decision makers, in addition to preferring more to less, are risk averse, with utility functions having positive, nonincreasing slopes at all outcome levels. Under SSD, an alternative with the cumulative distribution F(y) is preferred to a second alternative with cumulative distribution function G(y) if

$$\int F(y)\, dy \leq \int G(y)\, dy$$

for all possible values of y, and if the inequality is strict for some value of y. SSD has more discriminatory power than FSD, but still may not effectively reduce the number of alternatives. Graphically, because the accumulated area under F(y) in Figure 10.1 is always less than or equal to that under either G(y) or H(y), only F(y) is in the so-called SSD-efficient set of these three alternatives. When only G(y) and H(y) are considered, neither one dominates the other by SSD, since the accumulated area under G(y) is less than the area under H(y) for low values of y, while the opposite condition occurs at high values of y.

- **Stochastic dominance with respect to a function (SDWRF)** is a more discriminating efficiency criterion that allows for greater flexibility in reflecting preferences, but also requires more detailed information on those preferences. Formally stated, SDWRF establishes necessary and sufficient conditions under which the cumulative function F(y) is preferred to the cumulative function G(y) by all decision makers whose risk attitude lies anywhere between specified lower and upper bounds. The method is flexible enough to include and investigate the impact of any specified value (King & Robison, 1984).

PC-software has become available to perform the stochastic efficiency analyses (Goh *et al.*, 1989). This was also used to carry out the analyses for the example given in Table 10.1. Results are summarized in Table 10.2, together with the outcome of the previously discussed criteria.

*Table 10.2 Outcome according to the various decision criteria (US$). The preferred programs are underlined or indicated with an **

	Herd Health Programs	
Criteria	a_1	a_2
Maximin	1000	-10000
Minimax regret	10000	11000
Maximax	9000	19000
Hurwicz α rule (α = 1/2)	5000	4500
Laplace principle of insufficient reason	4667	4667
Expected monetary value	4400	4800
FSD	*	*
SSD	*	*
SDWRF (with risk aversion assumed to be):		
- low	*	*
- considerable	*	
- high	*	

Table 10.2 shows that choices appear to vary considerably among the criteria. The more risk averse types of criteria lead to choice of program a_1, while with the expected monetary value criterion (assuming risk neutrality) program a_2 is preferred. Under the so-called 'gambling' approach (ie, maximax), program a_2 is preferred even more strongly. The Laplace criterion (using equal weights for all outcomes) does not discriminate between the two programs. The same applies to most of the stochastic dominance criteria under

consideration. At higher levels of risk aversion (ie, with higher boundaries for the risk aversion interval), however, program a_1 is preferred again.

10.5 Bayes' theorem

Most farmers formulate subjective probabilities about uncertain decisions at a point in time. If additional information comes available, the farmer has to revise or update the probabilities. Many farmers appear to revise their subjective probabilities in an informal manner when they receive weather reports, national production estimates, data on domestic use and exports, price predictions, and other data that may affect their operation. Such probability revisions can be accomplished in a logical and mathematically correct manner by applying Bayes' theorem. Bayes' theorem is an elementary theorem of probability developed by the eighteenth-century English clergyman Thomas Bayes. This theorem is normally developed in introductory courses of statistics, and its logical validity is demonstrated in many books on decision theory (Anderson *et al.*, 1977; Barry, 1984; Boehlje & Eidman, 1984)

In Table 10.3 the major components that are needed to explain Bayes' theorem are summarized, some of which have been introduced already earlier in this chapter.

Table 10.3 Summary of the major components of a risky decision problem

a_j	= the j^{th} *act* or action available to the decision maker
θ_i	= the i^{th} *state of nature* or possible event
$P(\theta_i)$	= the *prior probability* of occurrence of θ_i
x_{ij}	= the *consequence, outcome* or *payoff* that results if a_j is chosen and θ_i occurs
z_k	= the k^{th} possible *forecast* from an experiment
$P(z_k\|\theta_i)$	= the *likelihood probability* of z_k occurring given that θ_i prevails
$P(\theta_i\|z_k)$	= the *posterior probability* of θ_i given forecast z_k
c	= the *cost* of the forecast device generating the set $\{z_k\}$ of possible forecasts

Suppose that the farmer in the example of Table 10.1 can obtain a prediction from the veterinarian of the probabilities of the events θ_i. The veterinarian may give k possible forecasts (k levels of the predictor; z_k). Since predictions of uncertain phenomena such as price and yield levels for agricultural production are less than perfect, it is important to consider the veterinarian's accuracy of the predictions in revising the prior probability estimates. The likelihood of obtaining a particular forecast, given the event that occurred $P(z_k|\theta_i)$, can be obtained by utilizing data on previous forecasts (z) of the veterinarian and the actual outcomes (θ). Then Bayes' theorem can be used to combine the prior probabilities $P(\theta_i)$ of the farmer and the data on the accuracy of the prediction $P(z_k|\theta_i)$ to estimate the posterior probabilities $P(\theta_i|z_k)$. The posterior probabilities indicate the probability that an event will occur given the prediction that has been made. Bayes' theorem can be expressed as:

$$P(\theta_i|z_k) = P(\theta_i)\,P(z_k|\theta_i) \,/\, \Sigma_i\,[P(\theta_i)\,P(z_k|\theta_i)] = P(\theta_i,z_k) \,/\, P(z_k)$$

In words, the first of these formulas says that the posterior probability of the i^{th} state, given that the k^{th} prediction has been made, is equal to the product of (1) the prior probability of the state, and (2) the likelihood probability of the prediction given the state, divided by all such products summed over all the states. As the second formula indicates, the numerator at the right-hand side is, by definition, just the joint probability of θ_i and z_k, while the denomi-nator is the unconditional probability of occurrence of the particular prediction z_k. In general, Bayes' formula can be considered a posterior probability (density) being proportional to prior probability (density) times likelihood. Bayes' theorem hinges on the definition of conditional probability ($P(A|B) = P(A \text{ and } B) / P(B)$).

Now we continue our example on selecting the best animal health program (Table 10.1). The farmer asks the veterinarian for advice. Based on past history, the farmer determined the accuracy of the predictions of the veterinarian. They are outlined in Table 10.4. The data indicate, for example, that if z_1 (good herd health) was predicted by the veterinarian in the past, a good herd health was found in 80% of the cases, an average herd health in 15% of the cases, and a bad herd health was never found. The values in other columns of the conditional probability matrix are interpreted in a similar manner.

Table 10.4 Likelihood probabilities of the veterinarian

	Likelihood probabilities $P(z_k\|\theta_i)$		
State of nature (θ_i)	z_1	z_2	z_3
Herd health good θ_1	0.80	0.20	0.00
Herd health average θ_2	0.15	0.70	0.15
Herd health bad θ_3	0.00	0.20	0.80

The farmer now wants to combine the predictions received with the prior probabilities using Bayes' theorem. The joint probabilities required for the numerator of Bayes' theorem have been calculated and recorded in Table 10.5. For example, $P(\theta_1)\,P(z_1|\theta_1) = 0.2 \times 0.80 = 0.16$. After completing the calculation of the joint probabilities, the denominator of Bayes' theorem can be calculated by summing each column. For example, $P(z_1) = \Sigma_i\,P(\theta_i)\,P(z_1|\theta_i) = 0.16 + 0.09 + 0.00 = 0.25$. Notice that summing the $P(z_k)$ for all values of k equals 1.

Table 10.5 Calculation of the joint probabilities

	Joint probabilities $P(\theta_i)\,P(z_k\|\theta_i)$		
State of nature (θ_i)	z_1	z_2	z_3
Herd health good θ_1	0.16	0.04	0.00
Herd health average θ_2	0.09	0.42	0.09
Herd health bad θ_3	0.00	0.04	0.16
$P(z_k)$	0.25	0.50	0.25

Following Bayes' theorem, the posterior probabilities can be calculated by dividing the joint probabilities by the unconditional probability of z_k. For example, $P(\theta_1|z_1) = 0.16 / 0.25 = 0.64$. The posterior probabilities are given in Table 10.6.

Table 10.6 Calculation of the posterior probabilities

	Posterior probabilities $P(\theta_i|z_k)$		
State of nature (θ_i)	z_1	z_2	z_3
Herd health good θ_1	0.64	0.08	0.00
Herd health average θ_2	0.36	0.84	0.36
Herd health bad θ_3	0.00	0.08	0.64

The posterior probabilities replace the prior probabilities estimated in Table 10.1. However, here are three sets of posterior probabilities, one for each predicted health situation (z_k). The next step is to calculate the EMV for each action using each set of posterior probabilities. For this, we first have to recalculate the payoff matrix taking into account the costs (c) of obtaining the prediction. Suppose that c equals US$200.

The results obtained, which are based on the payoff values of Table 10.1 and information cost of US$200, are shown in Table 10.7. For instance, the EMV of program a_1 given forecast z_1 is calculated as 1000 x 0.64 + 4000 x 0.36 + 9000 x 0.00 - 200 = US$(2080 - 200) = US$1880. Further inspection of Table 10.7 indicates that a_1 has the highest EMV for prediction of z_1 (denoted by underlining), while a_2 has the highest EMV if z_2 and z_3 are predicted. Thus the optimal strategy s^* for the farmer is $\{a_1, a_2, a_2\}$, meaning the farmer will maximize EMV by selecting program a_1 if z_1 is predicted, and selecting program a_2 if either z_2 or z_3 is predicted. This optimal strategy s^* is also called Bayes' strategy.

Table 10.7 EMVs based on posterior probability of θi given forecast zk and information cost c

	Forecast		
EMV[a]	z_1	z_2	z_3
Program a_1: $EMV(a_1|z_k)$	<u>1880</u>	3960	7000
Program a_2: $EMV(a_2|z_k)$	-4800	4720	13760

[a] Calculated as $EMV(a_j|z_k) = \Sigma_i\ [(x_{ij} - c)\ P(\theta_i|z_k)]$

10.6 Value of information

It is reasonable to ask whether the use of the predictor will increase the farmer's EMV. Moreover, there is a charge for veterinary services (cost c of the prediction). A farmer will like to know whether the increase in EMV exceeds the cost of the service. These questions can be answered by comparing the EMV using the optimal strategy with the predictor (Bayes' strategy) and the EMV for the optimal action without the predictor. If this value is negative, then the additional information provided by the forecast is not worth purchasing. The maximum price that should be paid for the forecast is given by the value of c for which these two EMVs (with and without the additional information) are exactly the same.

Now consider the case of a perfectly forecasting veterinarian. Since a **perfect predictor** is never wrong, it implies a posterior probability distribution of unity for some state of nature and zero for the rest. Thus, using a prime to denote perfection, there is a one-to-one correspondence between the k^{th} perfect forecast signal z_k' and some state of nature, say θ_i, so that we can denote the k^{th} perfect forecast by z_i'. Further, by Bayes' theorem $P(z_i') = P(\theta_i)$. With a perfect forecast device the optimal act can always be chosen. This results in the EMV of a perfect predictor. The EMV of perfect information can then be calculated as the difference between the EMV of the perfect predictor and the EMV without the predictor (ie, without additional information).

Let us return to our animal health example. The EMV of the optimal strategy with the additional information from the veterinarian, the Bayes' strategy s^* $\{a_1, a_2, a_2\}$ equals US$6270 (see Table 10.8). As the EMV of the optimal decision without the predictor (a_2) is US$4800 (see previous section and Table 10.8), the EMV of the forecast device turns out to be US$6270 - 4800 = US$1470. Because this value is positive, the additional information expected from the forecast device is worth purchasing.

Table 10.8 Value of information (in US$)

EMV of optimal decision (a_2) without additional information:
$\text{Max}_j\ [x_{ij}\ P(\theta_i)] = -10\,000 \times 0.2 + 5000 \times 0.6 + 19\,000 \times 0.2 = 4800^a$
EMV of optimal (Bayes') strategy ($s^* = \{a_1, a_2, a_2\}$) with additional information:
$\Sigma_k[\max_j \text{EMV}(a_j \vert z_k)]\ P(z_k) = 1880 \times 0.25 + 4720 \times 0.50 + 13\,760 \times 0.25 = 6270^b$
EMV forecast device: 6270 - 4800 = 1470
EMV of the optimal strategy based upon perfect predictor (z_i'):
$\Sigma_i\ [\max_j \text{EMV}(x_{ij} - c \vert z_i')\ P(\theta_i) = 800 \times 0.2 + 4800 \times 0.6 + 18\,800 \times 0.2 = 6800^c$
EMV of perfect predictor: 6800 - 4800 = 2000

[a] See Table 10.1 for $P(\theta_i)$ and x_{ij}

[b] See Table 10.5 for $P(z_k)$ and Table 10.7 for s^* and the corresponding EMVs

[c] See Table 10.1 for $P(\theta_i)$ and x_{ij}; c = US$200

The EMV of the optimal strategy based upon a perfect predictor is also determined in Table 10.8. The EMV of such perfect information is US$6800. So, the EMV of the perfect predictor is US$6800 - 4800 = US$2000. This makes the efficiency of our predictor relative to a perfect predictor, both assumed to cost US$200, (1470 / 2000) x 100% = 73.5%.

Exercise

Work through the example on decision analysis, a left-displaced abomasum case, in Chapter 19. For three different strategies, the payoff matrix is given. You have to find the best strategy according to different criteria: the EMV, the maximin, the minimax regret and the maximax criterion (as discussed in section 10.4). In the next part of the model you can practise working with a utility function and 'translating' this into risk attitude (see section 10.3). Lastly, the model leads you through the Bayes' theorem (see section 10.5) and calculations will be made on the value of information (see section 10.6). The time needed for this exercise is approximately 60 minutes.

10.7 Multiperson decision making

The model of risky choice, as outlined above, relates primarily to a situation where there is one decision maker whose beliefs and preferences are to be used in the analysis and who bears the consequences of the choice. Often, however, more than one person will be involved in any decision and/or affected by the consequences. Unfortunately, the extension of the methods of decision analysis to multiperson decision problems is not a simple matter. Three multiperson decision situations can be considered of particular importance in agriculture: (1) group choice situations, wherein a number of people are collectively responsible for a decision, (2) situations with many individual and independent decision makers, and (3) social choice situations, where the power of decision rests with government or one of its agencies, but where many people are affected by the consequences. The last one especially relates to compulsory programs for contagious disease control and, therefore, will now be discussed in more detail.

Policymakers often tend to react in a risk-averse fashion, fearing the personal consequences of being seen to have made decisions that turned out bad. The uncertainties of particular public projects or programs, however, are often rather insignificant when measured against the total performance of the economy. That is why economic theory teaches that governments make the best economic choice among risky projects by using risk-neutral decision rules, such as the expected monetary value criterion (Little & Mirrlees, 1974). There are two major reasons to consider risk-related decision rules to be appropriate for the choice among projects: (1) when they are unusually large, eg, affecting 10% or more of national income, or (2) when their consequences are not spread widely, and fairly evenly, among the population. The latter will often apply to contagious disease outbreaks, since losses primarily affect producers' income, especially on farms and in those areas that are actually affected by the disease (Berentsen *et al.*, 1990). A better insight into the potential consequences of the various decision rules and risk attitudes may be helpful anyway to provide useful information for a more thoughtful and rational decision-making approach. Stochastic dominance with respect to a function is commonly considered the most promising approach in this type of analysis, but requires at least some information on the policymakers' preferences concerning the outcomes. Empirical research to determine these preferences in agriculture has been sparse so far.

10.8 Concluding remarks

Risk and uncertainty are undoubtedly important in animal health management. Advice and modelling that are to support decisions in this area, therefore, should include appropriate (subjective) probability estimates for the relevant variables under consideration. Decision analysis and Bayes' theorem are considered worthwhile approaches for ensuring that farmers get advice and make decisions which are consistent with (a) their personal beliefs about the risks and uncertainties surrounding the decision, and (b) their preferences for the possible outcomes. It can also help to provide a more rational basis for decision making in the public domain, and to determine the economic value of additional information to reduce and/or predict the risks and uncertainties. **A good risky decision, however, does not guarantee a good outcome.** That would only be possible with perfect foresight (ie, in the absence of uncertainty). It does assure, however, that the decision made is the best possible one given the available information.

Appropriate decision rules are considered a major component of a risky decision problem (Boehlje & Eidman, 1984). The most widely used expected monetary value criterion does not always tell the whole story, as shown in the - simplified - example in this chapter. Less advanced criteria (such as maximin or minimax) are considered not to be appropriate from a theoretical point of view. Utility functions make it possible to provide the most comprehensive approach, including a trade-off between the average outcome and its variation, but will not always be easy to carry out and apply in actual field advice. Stochastic dominance criteria are commonly considered promising tools in this type of analysis. User-friendly software has become available to make the application of this type of advanced criteria much easier and accessible (Goh *et al.*, 1989).

References

Anderson, J.R., Dillon, J.L. & Hardaker, J.B., 1977. Agricultural decision analysis. Iowa State University Press, Ames, 344 pp.

Barry, P.J. (ed.), 1984. Risk management in agriculture. Iowa State University Press, Ames, 282 pp.

Berentsen, P.B.M., Dijkhuizen, A.A. & Oskam, A.J., 1990. Foot-and-mouth disease and export. Wageningen Economic Studies No. 20, Pudoc, Wageningen, 89 pp.

Boehlje, M.D. & Eidman, V.R., 1984. Farm management. John Wiley & Sons, New York, 806 pp.

Goh, S., Shih, C.C., Cochran, M.J. & Raskin, R., 1989. A generalized stochastic dominance program for the IBM PC. Southern Journal of Agricultural Economics: 175-182.

King, R.P. & Robison, L.J., 1984. Risk efficiency models. In: Barry, P.J. (ed.): Risk management in agriculture. Iowa State University Press, Ames, p. 68-81.

Little, I.M.D. & Mirrlees, J.A., 1974. Project appraisal and planning for developing countries. Heinemann Educational Books, London, 388 pp.

Smidts, A., 1990. Decision making under risk. Wageningen Economic Studies No. 18, Pudoc, Wageningen, 329 pp.

11

Application of portfolio theory for the optimal choice of on-farm veterinary management programs

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Objectives

From this chapter the reader should gain knowledge of:

- the application of portfolio theory to the efficient selection of veterinary interventions
- the use of mathematical programming techniques to identify the optimal combinations of interventions which maximize expected financial returns while minimizing risk

The chapter emphasizes the importance of including risk in addition to expected return when considering investment in on-farm veterinary services.

11.1 Introduction

The health management approach to the delivery of veterinary services has expanded greatly, providing significant economic benefits to dairy producers. Veterinarians are becoming increasingly aware of the need to consider the economic consequences of planned interventions for the farm business when designing herd health programs for farms (Dijkhuizen, 1992).

The decision-making process regarding investment in veterinary services is essentially similar to other farm management decisions which allocate land, labour and capital resources to alternative uses, the objective being to maximize net returns to the manager's owned resources. Economic concepts traditionally used for farm planning procedures such as the factor-product, factor-factor and product-product models have assumed either perfect knowledge of input-output and price relationships or the use of expected values. In reality, managers of agricultural businesses are constantly obliged to make decisions with less than perfect knowledge. Typically, they have only partial information on a number of possible outcomes and some feeling for the probability of each occurring over the planning period under consideration.

Expected return on investment is a commonly utilized measure of the relative economic worth of veterinary services (Ellis & James, 1979; Ngategize & Kaneene, 1985). The major assumption of this approach is that the variance of returns across all interventions is equal. This assumption is inappropriate when considering veterinary interventions, as the inherent biological variation of livestock production systems can often mask the more subtle effects of management changes designed to change production efficiency. Therefore, a more rigorous approach to the compilation of a herd health program as a mix of veterinary services should consider both expected outcomes and the degree of variability associated with each. The objective of this procedure is to determine the points where the trade-off between the dual objectives of maximizing expected return and minimizing risk is compatible with the herd manager's goals and attitude towards bearing risk.

Portfolio theory (Markowitz, 1952; Sharpe, 1970; Anderson *et al.*, 1977; Schneeberger *et al.*, 1982) evolved to address the problem of finding the portfolios (combinations of stocks, bonds, Treasury bills and other financial instruments), designed to concomitantly maximize expected return on investment while minimizing risk. In this context, risk is defined as the variance (or standard deviation) of expected returns.

11.2 Simulation data

Monte Carlo simulation (as described in Chapter 9) was used to investigate the economic consequences of six hypothetical components of a herd health program. The following production parameters were calculated for a 140-cow dairy herd served by the University of Pennsylvania Veterinary Services: heat detection efficiency (%), first- and other-service conception rates (%), average age of first breeding of heifers (months), calf and heifer mortality (%), somatic cell count linear score (SCC) and grain to milk ratio (kg of grain fed per kg of milk produced.) Data describing age, reproductive and production status of every female bovine in the milking and replacement herd at the time of the farm visit were collected and transcribed into a computer data file. Individual animal data in this file provided the demographic information of the herd upon which the simulation exercises were carried out.

In order to establish the likely performance of this herd without imposing a herd health program, production was simulated for a five-year period, using the estimated current levels of performance. The process was replicated five times using different random number seeds. Results from each set of runs were used to determine the expected value (mean) and standard deviation (risk) of performance indicators and profitability of the enterprise.

Next, a set of veterinary control programs were devised to improve the six parameters of herd performance noted above. The expected improvements were estimated from accounts of similar control programs reported in the literature and were felt to be achievable on this farm. Cost for each intervention was based on fees charged by the University of Pennsylvania, School of Veterinary Medicine and were assumed constant. It was also assumed that each intervention could be invested in incremental units and that the marginal response was constant.

Table 11.1 Estimated annual cost of simulated veterinary interventions

Feasible interventions	Annual Cost (US$) 140-cow herd
1. Improving heat detection from 45% to 70%	4655
The heat detection rate could be improved over this range by the use of detection aids and increasing observation time by 2 hours/day	
2. Improving conception rate	2900
First service: 26% to 45%	
Other service: 36% to 45%	
By routine identification of cows ready to breed	
3. Replacement heifer management	500
Lowering the minimum first breeding age of heifers from 600 to 450 days (18 to 15 months) by improved monitoring of weight and height	
4. Reducing calf mortality losses	400
5% to 1% mortality, by improved colostrum management and administration	
5. Improving mastitis control	500
Reducing somatic cell count (SCC) code from 5 to 4 by improved mastitis control through culturing clinical cases and routine milking machine and procedure evaluation	
6. Improving dairy nutrition	500
Reducing the grain to milk ratio by 10.7% (0.56 to 0.50 kg of grain per kg of milk), by utilizing a nutritional consultant and routine forage analysis	

Simulations involved imposing each intervention singly on the herd for the five-year period, with five replications. Each intervention considered is presented in Table 11.1 with a brief description of the procedures involved and the annual cost for the cooperating 140-cow herd.

For each replication of each alternative, the enterprise annual gross margin for each of the five simulated years was calculated. These, in turn, were discounted to provide net present values. Gross margin is defined as cash income minus variable expenses. Cash income included receipts from the sale of milk, calves, cull cows and surplus replacement heifers. Variable expenses included all feed and hired labour expenses, replacement heifer purchases, breeding fees, veterinary and medical expenses, utilities, fuel and supplies. Net present values of each replication were converted to annuities to provide a set of five single dollar amounts which represented a range of expected financial returns for each alternative. From each set of values, the expected value (mean) and risk (standard deviation) were computed to provide estimates of the annual enterprise gross margin over the five-year planning period under each regime (Table 11.2).

Table 11.2 Simulated five-year gross margin annuity values (US$/year) for dairy enterprise under each proposed intervention

		Proposed interventions					
Run	Control	Heat detection	Conception	Heifers	Calf mortality	Mastitis	Dairy nutrition
1	134993	190154	178937	137045	152446	144678	154638
2	146196	195844	188565	140752	142933	151557	165727
3	135966	190963	186326	149423	137449	145259	149000
4	132083	193430	176154	155848	137691	137238	155016
5	138449	192247	167140	147827	133477	158329	155340
Mean	137537	192528	179424	146179	140799	147412	155944
s.d.	4785	1999	7655	6627	6553	7099	5420

The difference in the annuity values between each intervention and the control option provides an estimate of their gross value. The **Expected Return On Investment (EROI)** was expressed as the ratio of the net value of the intervention divided by the annuity value equal to the cost of the program over the five-year period. For example, the procedure to estimate the value of improving heat detection efficiency from 45% to 70% is as follows:

Enterprise gross margin under intervention	US$ 192528
Enterprise gross margin for control situation	US$ 137537
Increase in gross margin attributed to intervention	US$ 54991
Annual cost of implementing intervention	US$ 4655

Expected return on investment (EROI) = (US$ 54991-US$ 4655)/US$ 4655 = 10.81
Standard deviation (s.d.) = 1.114
Expected values and associated standard deviations for each proposed intervention are shown in Table 11.3. These data are used in the application of portfolio theory to devise a total herd health program for this herd.

Table 11.3 Expected return and risk attributes of proposed interventions

	Proposed interventions					
	Heat detection	Conception	Heifers	Calf mortality	Mastitis	Dairy nutrition
EROI	10.81	13.44	16.28	7.16	18.75	35.81
s.d.	1.114	3.113	16.385	20.285	17.112	14.459

11.3 Portfolio model

The return and risk attributes of a total herd health program are determined by the number and mix of interventions included, and, specifically, by the proportion of available funds invested in each intervention. Portfolios exhibiting the lowest degree risk for a given level of return are considered most efficient. Selection of interventions from this efficient set will depend on the farmer's attitude towards risk. Studies have shown farmers to be risk averse in their selection of interventions (Binswanger, 1980; Dillon & Scandizzo, 1978). For the risk averse, any increase in risk must be offset by an appropriate increase in return: the more risk averse a particular individual becomes, the greater an increase in return will be required to counteract the extra riskiness. Regardless of the decision maker's risk preference, it is always desirable to select intervention combinations from the efficient set. To find the risk-efficient (E-V) frontier (minimum variance for each expected return), quadratic programming can be applied (Schrage, 1984):

$$\text{Minimize } V = x'Q$$

subject to:

$$rx \geq EROI_{minimum}$$
$$Ax \leq b$$
$$x \geq 0$$

where

V	= the variance of the mix;
x	= the vector of solutions;
r	= a given vector with the expected returns of the interventions;
Q	= a given matrix of variances and covariances across the interventions;
A	= a given coefficient matrix of constraints;
b	= a given vector of the right-hand sides of the constraints; and
$EROI_{minimum}$	= the minimum expected return on investment that would be acceptable.

Using the data from Table 11.3, we have:

Vector of Expected Returns:

$$r = \begin{bmatrix} 10{,}81 \\ 13{,}44 \\ 16{,}35 \\ 7{,}16 \\ 18{,}75 \\ 35{,}81 \end{bmatrix}$$

Covariance Matrix:

$$Q = \begin{bmatrix} 1.24 & 0 & 0 & 0 & 0 & 0 \\ 0 & 9.69 & 0 & 0 & 0 & 0 \\ 0 & 0 & 267.28 & 0 & 0 & 0 \\ 0 & 0 & 0 & 411.49 & 0 & 0 \\ 0 & 0 & 0 & 0 & 293.17 & 0 \\ 0 & 0 & 0 & 0 & 0 & 209.09 \end{bmatrix}$$

Note that the covariance terms in Q are zero. This is because of the assumption that the interventions considered are assumed to be independent. The objective is to find the combination (portfolio) of the six possible interventions that minimizes the total variance:

$$V = x'Qx$$

The n^{th} element of the solution vector x, x_n, is the proportion of funds that is to be invested in the n^{th} intervention.

The nature of quadratic programming permits the problem to be defined more strictly by the specification of further constraints. For example, the constraint:

$$\Sigma x_n = 1 \qquad n = 1, 2, ..6$$

ensures that x' be expressed as a percentage of available funds. Another constraint may limit investment in any individual intervention to some percentage of available funds. In this case, we set the limit at 50%:

$$x_n \leq 0.50 \qquad n = 1, 2, ..6$$

The final constraint to be imposed on this problem ensures that the expected return on investment (EROI) of the solution is above a minimum desired level:

$$rx \geq EROI_{minimum}$$

Specifying a minimum return on investment of 10, the problem is written as:

MINIMIZE: $1.24(x_1)^2 + 9.69(x_2)^2 + 267.28(x_3)^2 + 411.49(x_4)^2 + 293.18(x_5)^2 + 209.08(x_6)^2$

subject to

$$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 = 1$$
$$0 \leq x_1 \leq 0.50$$
$$0 \leq x_2 \leq 0.50$$

$$0 \le x_3 \le 0.50$$
$$0 \le x_4 \le 0.50$$
$$0 \le x_5 \le 0.50$$
$$0 \le x_6 \le 0.50$$
$$10.81(x_1) + 13.44(x_2) + 16.28(x_3) + 7.16(x_4) + 18.75(x_5) + 35.81(x_6) \ge 10$$

Quadratic programming was used to solve this problem. The linear programming package used was LINDO (Linear, INteractive, Discrete Optimizor) (Schrage, 1984). The solution is:

$x_1 = 0.50$ - improve heat detection
$x_2 = 0.44$ - improve conception rates
$x_3 = 0.02$ - reduce breeding age of replacement heifers
$x_4 = 0.01$ - reduce calf mortality
$x_5 = 0.01$ - improve mastitis control
$x_6 = 0.02$ - nutritional consulting

As the coefficients in the solution sum to unity, they indicate the number of cents in each available dollar that should be invested in each component of the dairy veterinary management program for this herd. If this is done, the return and risk characteristics of the program will be:

expected return: rx'	= US$12.64 per US$1.00 invested
variance: (x'Q)	= 2.43
standard deviation: (risk)	= US$1.56

11.4 *Parametric analysis*

When presented with the optimal mix of veterinary services, a farmer may be interested in how the solution might change as a greater minimum return on investment was demanded ($EROI_{minimum}$). Parametric analysis in linear programming is a technique that allows one to trace out how the solution changes as a specific coefficient changes (Hillier & Lieberman, 1990). Parametric analysis allows one to test the sensitivity of the solution to varying levels of the right-hand side value for any given constraint.

In our problem, the minimum expected return constraint ($EROI_{minimum}$) was varied between the limits of US$8.99 and US$27.28. The portfolio at the lower bound comprised a combination of the two interventions with the lowest expected return on investment: reducing calf mortality (7.16) and improving heat detection efficiency (10.81). At the upper bound, the portfolio consisted of improving mastitis control (18.75) and dairy nutrition (35.81). The combination with the smallest variance (V) was found for successive values of expected return between the boundaries.

The solution for the values at which the basis changes, ie, the points in the E-V frontier at which an intervention enters or leaves the quadratic linear program solution, is shown in Table 11.4. For example, reading from left to right, 'calf mortality' leaves the solution at an expected return on investment (EROI) of 14.09. Similarly, 'heat detection' falls out at EROI is 22.05. Lastly, 'heifer rearing' is dropped at EROI = 27.28, where 50 cents in each dollar should be spent on 'mastitis control' and 'dairy nutrition' respectively. Other optimal solutions occurring between these points are obtained by linear interpolation.

Table 11.4 Percentage composition of efficient herd health programs from results of parametric analysis

	Efficient herd health programs				
Interventions	**1**	**2**	**3**	**4**	**5**
Heat detection	0.50	0.50	—	—	—
Conception rates	0.44	0.38	0.50	—	—
Heifer rearing	0.02	0.02	0.06	0.11	—
Calf mortality	0.01	—	—	—	—
Mastitis control	0.01	0.02	0.08	0.38	0.50
Dairy nutrition	0.02	0.08	0.36	0.50	0.50
EROI	12.64	14.09	22.05	26.82	27.28
s.d. (risk)	1.56	1.81	5.67	9.51	11.21

A graph of the efficient sets of intervention combinations (programs 1-5 in Table 11.4) is shown as the line marked with 'crosses' (x) in Figure 11.1. These programs represent the most efficient combinations, offering the highest return at any risk level. Farmers who are

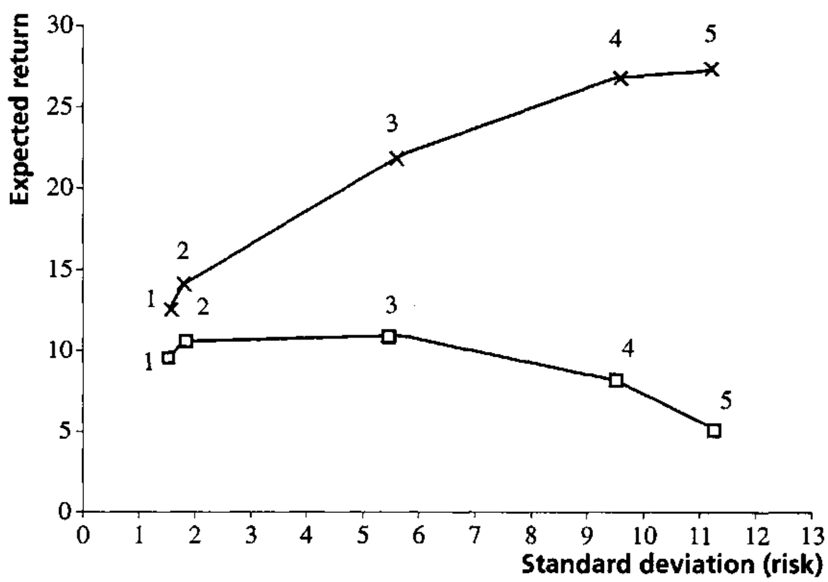

Figure 11.1 Expected return (US$) and risk (US$) associated with alternate efficient dairy veterinary management programs

risk averse would always prefer to select portfolios from the efficient set.
A further aspect of risk management is to ensure that returns never fall below a certain level. The line marked with little squares (□) shows the lower 95% confidence bound for the efficiency frontier, obtained by subtracting 1.96 standard deviations from the expected returns of each efficient portfolio.
The interventions that were selected for investigation were considered to operate independently of each other, and thus their correlation coefficients were all zero. This is not a necessary condition for risk reduction through diversification of interventions. Correlation coefficients range from -1 to +1, where pairs of interventions with correlation coefficients of -1 hold the greatest opportunity for risk reduction. In Figure 11.2, the expected return and risk of the combinations of 'mastitis control' and 'heifer rearing' are shown under varying degrees of correlation. The greatest risk reduction occurs when the correlation coefficient is at a minimum of -1.

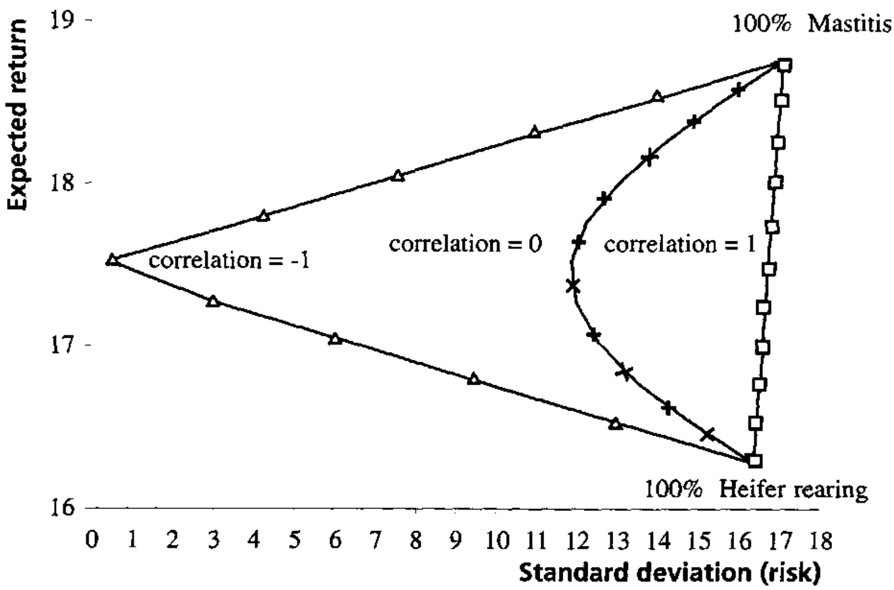

Figure 11.2 Expected return (US$) and risk of two interventions:mastitis control and heifer rearing

References

Anderson, J.R., Dillon, J.L. & Hardaker, J.B., 1977. Agricultural decision analysis. Iowa State University Press, Ames, 344 pp.

Binswanger, H., 1980. Attitudes toward risk: experimental measurement in rural India. American Journal of Agricultural Economics 62: 395-407.

Dijkhuizen, A.A., 1992. Modelling animal health economics. Inaugural speech, Wageningen Agricultural University, Wageningen, 28 pp.

Dillon, J.L. & Scandizzo, P., 1978. Risk attitudes of subsistence farmers in Northeast Brazil: A sampling approach. American Journal of Agricultural Economics 60: 425-435.

Ellis, P.R. & James, A.D., 1979. The economics of animal health - (1) Major disease control programmes. The Veterinary Record: 504-506.

Hillier, F.S. & Lieberman, G.J., 1990. Introduction to operations research. McGraw-Hill, New York, 954 pp.

Markowitz, H.M., 1952. Portfolio selection. Journal of Finance 7: 77-91.

Marsh, W.E., 1986. Economic decision making on health and management in livestock herds: examining complex problems through computer simulation. PhD-Thesis, University of Minnesota, St. Paul, 304 pp.

Marsh, W.E., Dijkhuizen, A.A. & Morris, R.S., 1987. An economic comparison of four culling decision rules for reproductive failure in the United States dairy herds using DairyORACLE. Journal of Dairy Science 70: 1274-1280.

Ngategize, P.K. & Kaneene, J.B., 1985. Evaluation of the economic impact of animal diseases on production: a review. Commonwealth Bureau of Animal Health, Veterinary Bulletin 55: 153-163.

Schrage, L. (ed.), 1984. Linear, integer, and quadratic programming with Lindo. The Scientific Press, Palo Alto, California, pp. 206-223.

Sharpe, W.F. (ed.), 1970. Portfolio theory and capital markets. McGraw-Hill, pp. 18-69.

12

Modelling the economics of risky decision making in highly contagious disease control

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Objectives

From this chapter the reader should gain knowledge of:

- the basic theory of demand and supply
- the concept of producer and consumer surplus
- the economic principles of quantifying the indirect losses due to export bans in case of contagious animal diseases

The approach is illustrated for foot-and-mouth disease outbreaks.

12.1 Introduction

In Chapter 2 on 'economic decision making in animal health management' it was shown that a producer's optimal level of output is determined by input prices, efficiency of the inputs used and output prices. Given sufficient data concerning a firm's production, it is possible to construct the production functions, and from those the average and marginal physical products. If also the output prices are known, the total, average and marginal return functions can be determined. These functions permit the location of the optimal (profit maximization) level of production for an individual firm.

Going beyond this, it is of interest to see how the input and output prices faced by the producer are determined. In market economies these are a result of demand and supply. **Demand** is the relationship between the market price of a good or service and the quantity people are willing and able to buy. **Supply** is the relationship between the market price and the quantity producers are able and willing to sell. The study of demand and supply, and the way they interact, forms a fundamental part of economics (Hill, 1980).

In this chapter, the development and interactions of demand and supply are examined. Special attention is focused on determining the losses due to market disruptions because of export bans. The basic underlying principles of these losses are presented and discussed, and illustrated for foot-and-mouth disease (FMD) outbreaks in the Netherlands (Berentsen *et al.*, 1990).

12.2 Demand and supply - the price mechanism in a market economy

It is common practice, and an invaluable aid to comprehension, to express demand and supply schedules in graphical form, with prices on the vertical axis and quantity on the other (see Figure 12.1). Such a graph is often called the scissors graph because of its shape; most demand curves slope downwards from left to right - more of the commodity is demanded as price falls - whereas supply curves slope upwards from left to right - more is supplied as price rises. Where the two curves cross is the equilibrium price at which the quantities demanded and supplied are in exact balance.

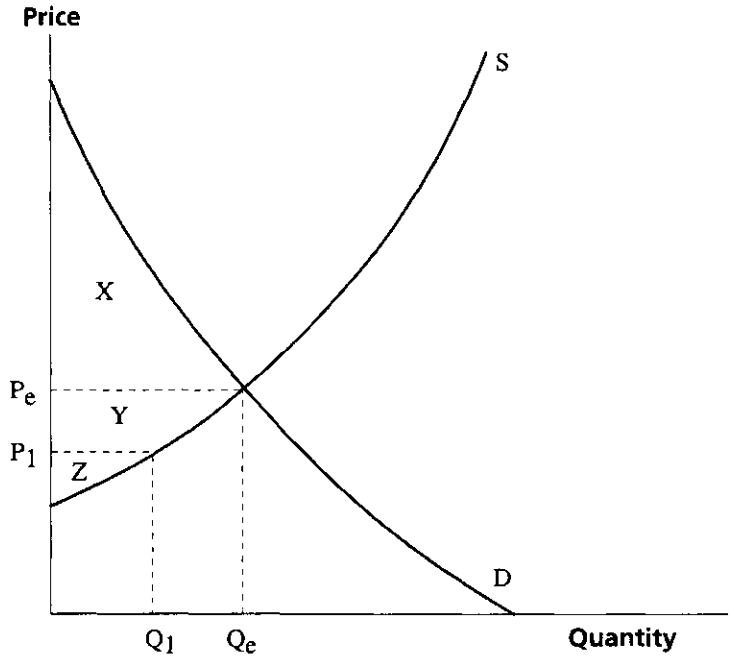

Figure 12.1 Demand (D) and Supply (S) curves

A measure of the responsiveness of the quantity demanded or supplied to changes in the market price of that good is referred to as the **price elasticity** of demand or supply respectively. Specifically, it is the percentage change in quantity divided by the percentage change in price. If the percentage change in price affects a larger percentage change in quantity, the demand or supply curve is called elastic (ie, price sensitive). Inelastic response refers to a smaller percentage change in quantity resulting from a given change in price. Agricultural products are characterized by rather steep (ie, inelastic) demand and supply curves (Hill, 1980). In other words relatively small changes in quantities may have large price effects.

The area between the supply and demand curves to the left of their point of intersection is very important with respect to the indirect losses from disease (Howe & McInerney, 1987).

It provides basic information on the welfare effects for producers, consumers and the society as a whole. For instance, the supply curve tells us that some producers would have been willing to produce in return for prices below P_e. To give an example, in Figure 12.1 the production of Q_1 units of output would have been realized for a price as low as P_1. In practice, all of those units of output which comprise the total of Q_1 sell at price P_e. Because the market determined a unit price of any commodity as a valuation, some farmers actually obtain more value (or benefit) from the sale of their products than they might necessarily have sought or expected. In other words, they obtain a kind of economic surplus. To be precise, this surplus equals P_e-P_1, not for the total production Q_1 but for the marginal unit of output at Q_1. When adding up the surpluses associated with all other units of output between the origin and equilibrium output Q_e, the total economic surplus is given by the area Y+Z in Figure 12.1. This total area measures what, for fairly obvious reasons, is called the **producer surplus**. By analogy, **consumer surplus** is equal to area X. All consumers pay P_e for each unit of the product, but some would be willing to pay more if supply was less abundant. They need not do so in the circumstances described, and so they benefit from getting their product cheaper than otherwise.

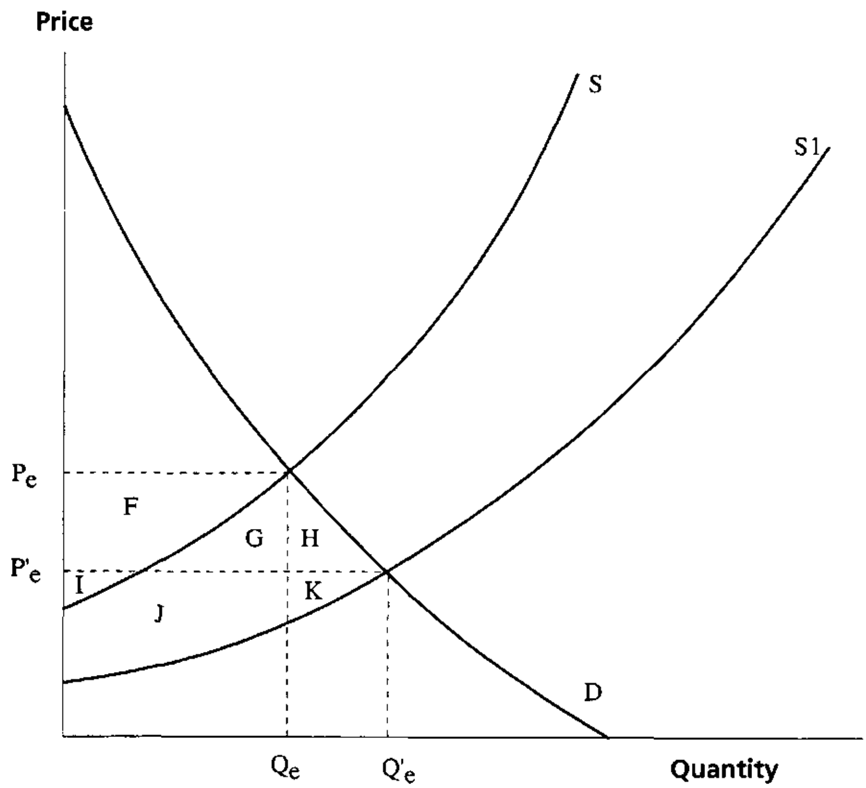

Figure 12.2 The change in consumer and producer surplus after reaching a new market equilibrium

By the same token, effective control of animal disease increases the (long-term) productivity of resources in the affected population. The outcome is to shift the supply curve for livestock products to the right, ie, farmers are able to produce more at whatever is the current price. This is illustrated in Figure 12.2

The welfare consequences of the change in Figure 12.2 can be summarized as follows:

	Gain	Loss	Net
Producers	I+J+K	F+I	J+K-F
Consumers	F+G+H	—	F+G+H
Society	(I+J+K+F+G+H)	(F+I)	(J+K+G+H)

Notice that it is not only possible to identify the net effects on producers and consumers respectively, but that it is also possible to summarize the consequences for a society as a whole, ie, for people irrespective of whether they are producers, consumers or both. Within the theory of welfare economics, however, there is a discussion about the aggregation of benefits and costs at the national level (Just *et al.*, 1982). Simple aggregation of these effects presumes an equal weight of benefits and costs for each group and individual, which is usually not the case. From an investigation of EU dairy policy over the years 1980 to 1987, for instance, it emerged that one dollar of producer income was considered twice the weight of one dollar of consumer income (Oskam, 1988). It is, therefore, recommendable to report both the separate effects for producers and consumers, and their equally-weighed total, leaving policymakers the opportunity to include their own weights.

12.3 Determining the indirect effects due to export bans

Outbreaks of contagious animal diseases are understandably feared, especially in major exporting countries such as the Netherlands. Control of this type of disease goes beyond the influence of the individual farmer, and needs to be carried out at national or even international level. To make economically sound decisions on this type of control, an integrated approach is required that includes the effects of different conditions and scenarios considering (1) the spread of the disease, (2) the direct cost of prevention and eradication, and (3) the indirect effects due to export bans. Research publications in this field are sparse and hardly go beyond the first two stages. Therefore, research was started to develop a method for quantifying and including the indirect losses owing to export bans (Berentsen *et al.*, 1990).

The basic principle for determining the indirect effects due to export bans is illustrated in Figure 12.3. This figure shows the supply curve (S) and the demand curve (D) for a country, exporting a certain product. At the basic price level P, producers supply amount Q_s, while consumers demand amount Q_d, with the difference (Q_s-Q_d) being exported. When export bans are in effect, a new equilibrium will arise at a lower price level, influencing the welfare of both producers and consumers.

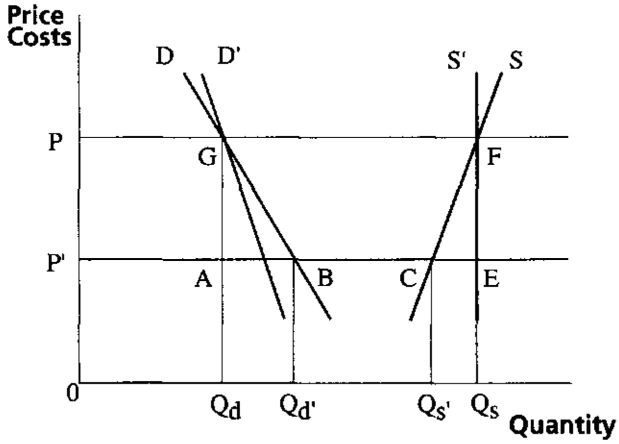

Figure 12.3 The market situation for a country, exporting a product

Assuming producers strive after maximum profits on competitive markets, the supply curve (S) is the same as the rising part of the marginal cost curve, the curve of which was indicated in Chapter 2. The producer surplus is formed by the gross returns (quantity times price) minus the variable costs (the area under the supply curve). This surplus can be considered the net return to fixed inputs. Consequently, the losses to the producers due to a drop in price from P to P' is the reduction in producer surplus (area PFCP'). In the short term, a large part of the costs is fixed and the supply curve will be steep. With disease outbreaks that do not last long, therefore, the vertical supply curve (S') can be used to quantify the losses in producers income. Actual losses to the producers are reduced by any compensation paid by the government. Consumers gain from a drop in price, indicated by the increase in consumer surplus (area PGBP'). From the alternative demand curve (D') it can be concluded that the slope of the curve (ie, the price elasticity of demand) influences the increase in consumer surplus.

12.4 Foot-and-mouth disease outbreaks as an example

12.4.1 Framework of the modelling approach

The economic feasibility of continued preventive vaccination is a regular topic for discussion in many countries still vaccinating. The discussion within the EU concerning this subject led to the decision to stop annual vaccination in all member countries, taking effect from 1 January 1992. In preparing this decision, research was carried out for the Netherlands to develop a dynamic modelling approach, integrating the epidemiological and economic aspects. First, a Markov chain model was designed in which the spread of the disease can be simulated for different control strategies, in a population with and without preventive vaccination. From the spread of the disease and the control strategy applied, the direct economic effects were calculated. Subsequently, this approach was further extended

by modelling the indirect effects of potential export bans, resulting in a user-friendly computer model which makes it easy to determine the impact of uncertain epidemiological and economic input values (Berentsen *et al.*, 1990).
In Figure 12.4 a flow chart is presented of the entire modelling approach, including three submodels (the epidemiological model, the disease control model and the export model) and an integrating part. For each of the strategies under consideration the annual costs of following a specific strategy are calculated using the three models and the integrating part.

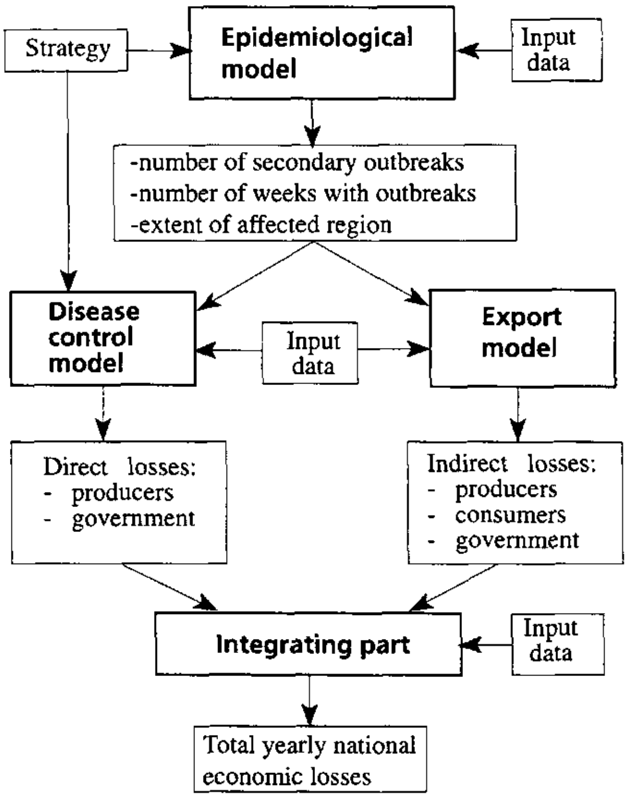

Figure 12.4 An overview of the FMD-modelling approach

In the epidemiological model the spread of the disease after a primary outbreak is simulated, taking into account the control strategy under consideration, disease specific input values and demographic data. Relevant output to be used for further - economic - calculations concerns the number of secondary outbreaks that follow a primary outbreak, the number of weeks with outbreaks and the size of the infected area. The disease control model calculates the direct losses to producers and government and asks for additional input data on the costs of ring vaccination, the costs of stamping out and the costs of idle production factors for farmers and industry. The export model calculates the indirect losses to producers, consumers and government and requires a specification of: (a) the products, affected by trade embargoes, (b) the markets to which these products are delivered, and (c) the actual reactions on these markets. Finally, the integrating part is used to quantify the yearly national economic losses from following the specific strategy, combining the direct and indirect financial losses. For these calculations additional input is required on: (1) the expected frequency of primary outbreaks, (2) the costs of yearly routine vaccination, and (3) the price premium for the products under consideration of getting access to FMD-free markets. In the entire modelling approach, about 80 input parameters can be modified.

12.4.2 Assumptions underlying the export model

The export model is product-oriented, ie, the effects of export bans on producer and consumer income and on the government budget are calculated for each product separately (ie, meat and cattle in case of FMD). In calculating these effects, it is necessary to know the market structure for each product. The market structure is described by the number of markets to which the product is exported and by the following characteristics per market: the volume of export, the level of consumption, the price elasticity of demand and the transport costs per unit of product. For the domestic market, also import and price of the product are of importance.

Some countries (such as the USA, Japan and South Korea) do not accept meat from countries with an annual FMD-vaccination scheme. As a result the price for meat paid on this so-called FMD-free market is about 10% higher than on other markets. This is the reason to assume that the market structure will change after ceasing annual vaccination. So, for a correct evaluation of strategies it is necessary to define a market structure per product for both, a situation with and without annual vaccination.

In calculating the indirect effects, it is necessary to know what reactions from importing countries can be expected in case of an FMD outbreak in the Netherlands. Within the EU, countries usually close their borders for meat and cattle from only the infected area until four weeks after the latest outbreak. Some countries outside the EU close their borders for these products from the entire country, until one or two years after the latest outbreak. In simulating the price effects of temporary export bans, the following assumptions are essential: (1) the reaction of producers to temporary changes in prices. Because an FMD outbreak is likely to be temporary, producers are assumed not to react to changes in prices of agricultural products, and (2) the way in which market prices and quantities react in the short term to changes on export markets. It is quite normal in models of international trade to consider markets completely fluid: if quantity changes, this will be apparent on the complete market. Such an assumption, however, is not very useful in the FMD approach because short-term reactions are not fluid at all. Therefore, the following additional assumptions were made: (a) there is a capacity limit for each export market, which is related to the usual volume of the export, (b) increasing exports to a particular market can only be realized by means of a price reduction (derived from the export demand curve for this particular market), and (c) the storage behaviour of participants on the market follows a rational approach: producers store products when the expected future market price minus the storage costs is higher than the present market price. The basic principles of this approach are illustrated in Figure 12.5.

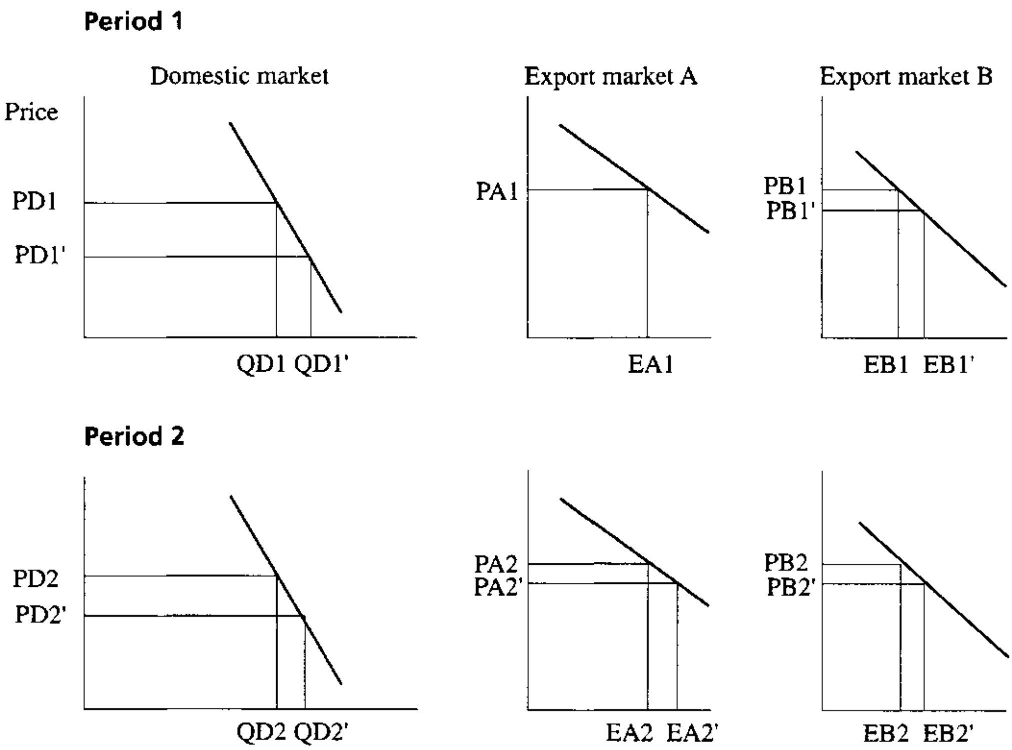

Figure 12.5 Basic principles of the export model

Here, country A imposes an export ban in period 1: the exports fall from EA1 to 0. Owing to this export ban, domestic prices and export prices decrease from PD1 to PD1' and PB1 to PB1' respectively. The export quantity to country B is limited to EB1'. A part of the production in the first period will be stored (and brought on the market again in period 2). This storage is just that size that PD1' plus the storage costs equal PD2'. In period 2, market participants face a market situation with an open export market again for country A. Also in period 2, additional exports to markets A and B are limited by the capacity limits (being set at 10% of the normal export).

12.4.3 Modelling outcome with respect to annual vaccination

Table 12.1 presents the losses resulting from a primary outbreak in the Netherlands in a situation with and without annual vaccination respectively.

Table 12.1 Economic losses resulting from a primary outbreak

	Vaccinated population		Non-vaccinated population		
Strategy [a]	**Ia**	**Ib**	**IIa**	**IIb**	**IIc**
Number of herds removed	33	27	688	240	138
Direct losses (US$ m)	4	4	100	36	20
Weeks with market disruption	60	58	81	112	60
Indirect losses (US$ m)	124	113	370	367	238
of which:					
- *producer losses*	*195*	*179*	*539*	*521*	*350*
- *consumer losses*	*-71*	*-66*	*-169*	*-154*	*-112*
Total losses (US$ m)	128	117	470	403	258
Annual losses (US$ m)	39	37	26	19	5

[a] Stamping out infected farms (Ia and IIa); stamping out infected farms plus ring vaccination (Ib and IIb); stamping out infected and risky contact farms (IIc).

The highest number of secondary outbreaks occur, as could be expected, in a non-vaccinated population with stamping out infected herds as the only control strategy (Table 12.1). Routine vaccination, however, is not necessarily the only remedy against a dramatic spread of the disease. The total number of outbreaks and the period of time over which they occur can also be considerably reduced by eradication of risky contact herds as well (IIc). However, it is doubtful whether public opinion would allow the slaughter of animals from herds without clinical signs of the disease.

The calculated direct losses show to be highly related to the length and extent of the outbreak. The indirect losses are by far the highest in the situation without yearly vaccination (as could be expected). This is mainly caused by the considerably longer-lasting reactions on the FMD-free markets.

The final comparison of strategies is done on a yearly basis, taking into account the expected frequency of primary outbreaks (ie, once each 5 years in a vaccinated population and once each 10 years in a non-vaccinated population), the total costs per outbreak, the costs of yearly vaccination and the extra profits from export to FMD-free markets. Strategies without yearly vaccination turn out to be the most preferable, despite the higher costs in case of outbreaks.

12.4.4 Risky decision making on control strategies

The model of Berentsen *et al.* (1990) was further used to simulate total losses in a non-vaccinated population for two control options under consideration, ie, stamping out and ring vaccination, with outbreaks occurring in three different areas of the Netherlands considering herd density and five different levels of disease spread within each area. Herd density ranges from relatively low to medium to high for Dutch conditions, with 2.1, 3.3 and 4.4 cattle and pig herds per km^2 respectively.

Table 12.2 Simulated losses from a theoretical outbreak of foot-and-mouth disease in a non-vaccinated population in the Netherlands (US$ m)

		regional livestock density (herds per km^2)					
		low (2.1)		medium (3.3)		high (4.4)	
Dissem. rate (i)	P(i)	stamp. out	ring vac.	stamp. out	ring vac.	stamp. out	ring vac.
dr-30%	0.05	248	360	282	379	318	390
dr-15%	0.20	279	370	341	392	451	416
default[a]	0.50	326	377	495	416	736	448
dr+15%	0.20	444	394	769	447	1658	500
dr+30%	0.05	591	411	1622	493	3154	577

[a] The default values were assumed to range (ie, to decline) from 3.8 in week 1 to 0.7 in week 6 and further in the region with a low livestock density, from 4.5 tot 0.8 in case of a medium density, and from 5.3 to 0.9 in a high-density region.

Disease spread within each area was based on default values for the dissemination rate *dr* (indicating the average number of farms to which the virus is spread by one affected farm), as well as on values that were set at 15% and 30% above and below default. Probabilities for these 5 classes of dissemination rates to occur were assumed to be symmetric, ie, 0.05, 0.20, 0.50 (default class), 0.20 and 0.05 respectively. The simulated outcomes for a theoretical outbreak of foot-and-mouth disease in the Netherlands are summarized in Table 12.2.
The choice based on the most likely outcome of the deterministic simulation model (presented under 'default') would be to apply the stamping-out strategy in case of an outbreak in the area with the low herd density, and ring vaccination in the others. This choice, however, does not hold for all situations considering disease spread and may lead to a considerable increase of losses in some of the cases. An above-normal dissemination rate, for instance, would make ring vaccination rather than stamping out to be the strategy that results in the lowest losses in the area with the lower herd density. A similar (but opposite) change occurs in the other areas with below-average dissemination rates. This is a classical example, therefore, of decision making under risk and uncertainty. Combining the simulated losses from Table 12.2 and the stochastic dominance rules, as described in Chapter 10, provides the outcomes presented in Table 12.3.
The first-degree stochastic dominance rule (FSD) cannot rank the strategies in any of the areas, because each respective pair of cumulative distributions intersects (as shown in Table 12.2). The more powerful second-degree stochastic dominance rule (SSD) does provide a preference for the areas with medium and high herd densities (ie, ring vaccination), but not for the low one. In case of a risk-averse attitude, therefore, stamping out no longer ranks highest in areas with a low herd density, as was the case with, among other things, the expected monetary value criterion. Stochastic dominance with respect to a function (SDWRF) shows, however, that at the lower levels of risk aversion the stamping-out strategy is still preferred. Ring vaccination becomes the dominating strategy when risk aversion is high.

Table 12.3 Stochastic dominance rules to rank the control strategies in case of a theoretical outbreak of foot-and-mouth disease in a non-vaccinated population in the Netherlands

	regional livestock density (herds per km²)					
	low (2.1)		medium (3.3)		high (4.4)	
Decision rules	**stamp. out**	**ring vac.**	**stamp. out**	**ring vac.**	**stamp. out**	**ring vac.**
FSD	*[a]	*	*	*	*	*
SSD	*	*		*		*
SDWRF,with risk aversion:						
-low	*			*		*
-considerable	*	*		*		*
-high		*		*		*

[a] Indicates the dominant strategy. With FSD the two strategies turn out to be equally dominant in all three areas under consideration. The same occurs with SSD and one of the SWDRF-alternatives in the area with the low herd density.

12.5 Concluding remarks

Indirect losses due to export bans can be of major importance with respect to foot-and-mouth disease outbreaks, as shown in this chapter. A further increase of trade between countries calls for an accurate and coordinated policy for contagious animal diseases. To anticipate these demands, a modelling environment is desired in which 'what-if' scenarios can be performed to explore the epidemiological and economic effects of the various diseases and control strategies. This requires input flexibility regarding (1) the type and density of farming in the region or country under consideration, (2) the type of disease, (3) the prevention and control strategy to apply, (4) the extent and segmentation of export markets, including intervention possibilities, (5) the country-specific probabilities of trade restrictions, and (6) the various prices and demand/supply elasticities. A combined approach across countries would make it possible to examine the impact of a coordinated strategy within a group of trading partners. The system thus derived will be a flexible tool to support real-life policy-making in an increasingly important area (Jalvingh *et al.*, 1995).

References

Berentsen, P.B.M., Dijkhuizen, A.A. & Oskam, A.J., 1990. Foot-and-mouth disease and export. Wageningen Economic Studies nr. 20. Pudoc, Wageningen, 89 pp.

Hill, B., 1980. An introduction to economics for students of agriculture. Pergamon Press, Oxford, 346 pp.

Howe, K.S. & McInerney, J.P. (eds), 1987. Disease in livestock: economics and policy. EUR 11285 EN, Commission of the European Communities, Brussels, 190 pp.

Jalvingh, A.W., Nielen, M., Dijkhuizen, A.A. & Morris, R.S., 1995. Computerized decision support system for contagious disease control. Pig News and Information 16: 9N-12N.

Just, R., Hueth, D. & Schmitz, A., 1982. Applied welfare economics and economic policy. Prentice Hall, Englewood Cliffs, 491 pp.

Oskam, A.J., 1988. Model building for the dairy sector of the European Community. PhD-Thesis, University of Amsterdam, Amsterdam (in Dutch, English summary), 225 pp.

13

Risk analysis and the international trade in animals and their products

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Objectives

From this chapter the reader should gain knowledge of:

- risk analysis
- risk assessment
- risk management
- risk communication

The basic principles are illustrated with some examples, focusing on the importation of animals and animal products.

13.1 Introduction

The incentives to develop a structured, objective, repeatable and transparent process of risk analysis have followed important changes in the social and political factors governing world trade. The conclusion of the Uruguay Round of the General Agreement on Tariffs and Trade (GATT) has led to an international agreement to remove barriers to trade in agricultural products, except in situations where such trade can be demonstrated to jeopardize the animal, human or plant health of the importing country. The discipline of **risk analysis** is being developed to give decision makers the means to assess whether or not particular trade proposals do, indeed, jeopardize the animal, human or plant health of the importing country and to demonstrate to interested parties the basis on which approval to import is granted or refused[1].

While acknowledging the intuitive appeal of a 'zero risk' policy to conservative sectors of a nation's livestock industries, the pursuit of such a 'zero risk' policy is counterproductive globally and domestically (Kellar, 1993). There is only one 'zero risk' policy and that is total exclusion of all imports. Even a total prohibition on importation of animals and animal products would not achieve 'zero risk' because people still travel and, if legal avenues are unavailable, people will find ways to import illegally.

In an important introduction to the subject of risk analysis, Kellar (1993) counters the

[1] In this chapter risk is approached from a veterinary perspective, while in the previous two chapters this was done from an economic point of view (ie, decision making under risk). The two approaches differ in their objectives, but can complement each other.

unattainable 'zero risk' with the recently established GATT principles that quarantine measures applied in the name of protecting animal health should be based on sound science and risk assessment methods and should not be used as disguised barriers to trade. He also makes the point that risk analysis, like epidemiology, must deal with situations as they arise and tolerate the mathematical limitations of the animal disease prevalence estimates or other such data on which it is based.

When analysing the risks associated with a proposed importation of animals or animal products it must be remembered that such imports cannot be made without some element of risk. The benefits of the imports often accrue to a relatively small group of people only, usually the entrepreneurs, initial importers and distributors of the new genetic material. The risks, on the other hand, are borne by a much broader group which includes all livestock owners whose animals could be infected with an exotic disease, as well as the general public who may be expected to bear the cost of containing and eradicating an outbreak of exotic disease. For these reasons a risk analysis may include a cost-benefit analysis of the proposed importation. However, importation may nevertheless be permitted even in the absence of any demonstrable national benefit. For example, the New Zealand Ministry of Agriculture's policy is that every citizen has the right to import unless the risk to agricultural security precludes importation. Such a policy presupposes that the quarantine service is charged with making judgments about the risks, and therefore the costs which may be imposed on the agricultural community, but does not sit in judgment on what are commercial decisions.

13.2 Terminology

The terminology of risk analysis has not been standardized and this can lead to confusion. So far, attempts to standardize terms have not been successful. Recognizing this, the journal *Risk Analysis* requires each article to define key terms in the context of that particular article. The Animal and Plant Health Inspection Service (APHIS) of the United States Department of Agriculture has proposed a standardized nomenclature for animal health risk analysis (Ahl *et al.*, 1993) and, with one exception, the present discussion follows the nomenclature proposed by APHIS.

13.3 Analysis of risk

Risk, as it relates to the importation of animals or animal products, is a measure of the probability of the introduction of an exotic disease and the seriousness of such an outcome. **Risk analysis** is a blend of art and science and is considered to comprise risk assessment, risk management and risk communication (Ahl *et al.*, 1993).

However, in any risk analysis it is important that **risk identification** be carried out adequately. If a particular risk is not identified, then steps to reduce it cannot be formulated. Many failures of quarantine are attributable to a failure of risk identification rather than risk assessment or risk management. For this reason, it can be stated that risk identification is of sufficient importance to warrant consideration as a subdiscipline in its own right.

In evaluating a proposal to import animals or animal products the first step is to draw up a comprehensive list of all the pathogens which could be associated with the species or commodity under consideration and then identify the possible routes by which these could come into contact with susceptible animals in the importing country.

Risk assessment is the process of estimating, as objectively as possible, the probability that an importation would result in the entry of an exotic disease agent and that local livestock would be exposed to that agent. Risk assessment ought to examine the effect of the introduction of an exotic disease. However, very few studies of this nature have been carried out anywhere.

In risk studies it is common to use 'risk' synonymously with the likelihood of occurrence of a hazardous event. In such instances, the magnitude of the event is assumed to be significant (Ahl *et al.*, 1993).

Risk management is the process to identify and implement measures which can be applied to reduce the risk to an acceptable level and document the final import decision. This process is also called risk mitigation or hazard mitigation.

Risk communication is the process by which the results of risk assessment and risk management are communicated to decision makers and the public. Adequate risk communication is essential in explaining official policies to stakeholders, such as established livestock industry groups, who often perceive that they are exposed to the risks but not the benefits of importations. Risk communication must also be a two-way process, with stakeholders' concerns being heard by officials and addressed adequately.

Having identified the possible risks posed by a proposed importation, the next stage in risk analysis is an assessment of the risk entailed by an unrestricted importation of animals or animal product under consideration. Risk assessment takes into account the prevalence of pathogens in the source population, the probability of pathogens surviving in the animal or product during the process of importation, the probability of the pathogen coming into contact with local livestock after importation and the seriousness of such contact.

There is a substantial body of information on the survival of pathogens in many animal products and, theoretically, each of the other factors should be amenable to being quantified in a similar objective and scientific fashion. In reality, at the present time it is often not possible to quantify them adequately. Much of the assessment ends up being based on guesswork and is thus potentially controversial and open to challenge from either domestic interest groups or overseas trading partners.

Risk management, on the other hand, is usually able to be quantified more objectively. For instance, there should be very little debate over the sensitivity of a particular serological test, or the efficacy of a particular embryo washing regimen for a specific pathogen on embryos of a given species.

13.4 Managing risk

Consider, for example, a serological test having a sensitivity of 0.95 when applied to animals infected with a particular disease agent. The probability of missing a single infected individual is 0.05. However, the predictive value of a diagnostic test is also a function of the prevalence of infection in the population under test. The probability that an animal which is negative to a given test is actually infected is calculated as follows (Marchevsky *et al.*, 1989):

$$P(I \mid N) = \frac{p\,(1\text{-}s)}{p\,(1\text{-}s) + (1\text{-}p)e}$$

where

$P(I \mid N)$	= the probability of the event of an animal being infected given that it is test-negative;
p	= the true prevalence;
e	= the specificity of the test; and
s	= the test sensitivity.

In matters of quarantine, the exclusion of 'false positive' animals is seldom of major concern, so this discussion assumes that specificity, e = 1. With a test of sensitivity, s = 0.95, the probability of a given test-negative animal actually being infected varies with prevalence, p, as illustrated in Table 13.1. It can be seen that as the prevalence of infection in the source population increases, the probability of a given test-negative animal being infected also increases.

Table 13.1 Probability that a test-negative animal is actually infected, given a test sensitivity of 0.95 and specificity of 1

Prevalence	Probability (I|N)
0.01	5.05×10^{-4}
0.05	2.62×10^{-3}
0.1	5.52×10^{-3}
0.2	1.23 x 10-2

Similarly, at any given prevalence, the probability of including a test-negative infected animal in an importation increases with the number of animals in the group to be imported. The probability of including even one test-negative infected animal (c) in a group of n animals can be calculated thus (Marchevsky *et al.*, 1989):

$$P(c \geq 1 \mid N) = 1 - \left\{ \frac{(1\text{-}p)e}{(1\text{-}p)e + p(1\text{-}s)} \right\}^n$$

The effect of increasing the size of the group destined for import is illustrated in Table 13.2.

With some diseases a policy decision may be made that a positive test result will disqualify only the individual animal which reacted positively to the test. The risks one takes with such a policy are illustrated in the examples just discussed (Tables 13.1 and 13.2).

Table 13.2 Probability that a test-negative infected animal will be included in a group destined for import (prevalence = 0.01, sensitivity = 0.95, specificity = 1, entire group tested)

n	If reactor animal only excluded P(c ≥1 I N)	If a single reactor disqualifies group P of no test positives
100	4.92×10^{-2}	5.00×10^{-2}
200	9.61×10^{-2}	2.50×10^{-3}
300	1.41×10^{-1}	1.25×10^{-4}
400	1.83×10^{-1}	6.25×10^{-6}
500	2.23×10^{-1}	3.13×10^{-7}

However, with some other diseases (often OIE List A diseases), it may be decided that a positive test result in any one animal will disqualify the entire group intended for importation. In such cases the probability of disqualifying an infected group increases as prevalence and/or the size of the group increases. The probability of a given test failing to detect at least one test-positive animal in an infected group, thus identifying the group as infected, can be calculated thus (MacDiarmid, 1987):

$$\beta = [1 - ts/n]^{pn}$$

where t is the number of animals from the group which are tested.

The difference in risk between the two policies is illustrated in Table 13.2. It can be seen that where the presence of a single reactor animal disqualifies the entire group destined for export, rather than just the reactor animal itself, the risks of an infected animal being imported are significantly reduced.

Whether a positive result to any one test disqualifies only the affected individual or the whole importation, the risks of importing unwanted disease can be further reduced by imposing a series of **safeguards**. When a series of safeguards is applied to an importation it may be relatively easy to quantify the amount by which the risk is reduced, even if consensus on the magnitude of the initial, unrestricted risk cannot be attained.

At this point it is appropriate to look at some examples of risk analysis. Many other examples can be found in Acree & Ahl (1991) and Morley (1993).

13.5 Examples

13.5.1 The risk of introducing anthrax by importing green hides

In reviewing the conditions governing the importation of hides and skins into New Zealand, Harkness (1991) outlined an approach to assessing the risk of introducing anthrax through the importation of green hides from Australia. The method used was based on one developed in Australia to assess the risk of introducing transmissible gastroenteritis of swine in pigmeat, and which has been described elsewhere (MacDiarmid, 1991).

The annual probability (T) of anthrax introduction via the medium of unprocessed hides is related to the probability (p) that a hide contains anthrax spores and to the number of occasions (n) that susceptible animals are exposed to contact with those spores. The number of occasions that contact with spores causes infection follows a binomial distribution, so that the chance of introduction of infection is:

$$T = 1-(1-p)^n$$

But when T is small, (eg, less than 0.001) the expression above approximates to the following:

$$T = pn$$

which simplifies the interpretation of the estimate of T and is the basis of the present estimates.
To assess the probability of anthrax spores being present, the following assumption is also made:

$$p = ise$$

where

i = the probability that an Australian animal was infected with anthrax at the time of slaughter. (The average number of officially confirmed cases of anthrax during the period 1970-1981 was 19 per year [range 9-42] and, without reference to the continuing decline in case numbers over many years, the maximum expected incidence was calculated at 40 cases per year. Total slaughterings of sheep and cattle in Australia in 1989/90 were about 40.23 million, a figure stable since 1980/81 [range 37.2 - 42.3 million]. The value of i was therefore estimated at 40 / 40.23 million = 0.000000994 or 9.94×10^{-7}.)

s = the proportion of spore infectivity surviving pre-export handling. (Since the spores of the anthrax bacillus are extremely resistant to adverse environmental conditions survival rates are considered to be very high, s was estimated at 90% (range 75% - 95%); s = 0.9.)

e = the proportion of green Australian hides among all rawstock processed in New Zealand. (Approximately 38.4 million sheep and 3.1 million cattle are slaughtered in New Zealand annually, an estimated 31% of New Zealand produced hides and skins are processed in the country, amounting to 13.5 million pieces annually. The estimated annual import volume from Australia for green skins is 0.92 million [range 0.90 - 1.40 million]. Thus e was estimated at 0.92m / 13.5m = 0.068.)

Thus p was estimated as 0.068 x 0.9 x 0.000000994 = 0.000000061 or 6.1 x 10^{-8}
The number of occasions per year on which susceptible animals are likely to be exposed to contact with anthrax spores was calculated as follows:

n = gtvf

where

g = the number of Approved Tanneries in New Zealand. (g = 23; Ministry of Agriculture and Fisheries records.)
t = the proportion of Approved Tanneries operating with a risk of contaminating pastureland by wastewater during flood periods. (No satisfactory information was available at the time the assessment was made. Waste drainage is controlled by local authorities under the appropriate legislation. Estimated proportion presenting risk was 10-20% so t was assumed = 0.2.)
v = the average number of days per year on which flooding occurs on pasture downstream of tanneries. (Estimated range was 20-30 days per annum, so v = 25.)
f = the probability of processing contaminated material during flood periods. (Calculated as average number of days of flooding divided by days worked, around 25 / 235. Therefore f = 0.11.)

Thus n was estimated as 23 x 0.2 x 25 x 0.11 = 12.65.

The calculations therefore indicate that the probability of introducing anthrax in any one year is:

T= 0.000000061 x 12.65 = 0.000000772 or 7.72 x 10^{-7}
(ie, less than one in a million)

The risk is likely to be even lower when one considers that the probability of livestock encountering the anthrax organism on any contaminated pasture is less than 1 and that ante- and post-mortem inspection at Australian abattoirs is highly effective in preventing anthrax cases being processed for their hides.
A risk assessment method must include some estimation of the degree and source of uncertainty associated with predicting the likelihood of introducing an animal disease as otherwise decision makers tend to focus on one single possible outcome, possibly at their peril. The weakness of a deterministic model such as the one just described is that it does not give the decision maker any estimate of the uncertainty of the risk estimate. As most of the variables are only estimates of what is most likely, the 'real' risk estimate will be shrouded in uncertainty. A Monte Carlo or Latin hypercube simulation model, using a personal computer software program such as @RISK (see also Chapter 18), allows each of the variables to be represented as a range of values and then, by a series of iterative calculations,

presents the final risk estimate as a probability distribution. Addressing uncertainty is one of the most valuable contributions modern risk analysis brings to the field of quarantine.

13.5.2 OIE list A diseases and embryo transfers

The development of embryo transfer techniques, whereby embryos may be recovered from donors in one country, frozen and transported internationally before being implanted into recipients in another country, has opened the way for the relatively low risk introduction of new bloodlines. The importation of genetic material by embryo transfer carries considerably less risk of introducing exotic diseases than does the importation of live animals or semen. However, while there is available evidence indicating that many pathogens are unlikely to be transmitted along with embryo transfers, caution must be exercised because in many cases the number of experiments has been so small that the upper limit of a 95% confidence interval for the probability of disease transmission is still rather high.

To be 95% confident that transmission does not occur between viraemic donor and susceptible recipient in, say, more than one transfer in 100, transfers would need to be carried out with negative results on 300 occasions. Such large-scale experiments are expensive and have been conducted for a relatively small number of pathogens only. For this reason many countries operate a quarantine policy of excluding an entire importation if any individual within it is found to be positive in a test for one of the OIE List A diseases.

By taking into account factors such as sensitivity of the diagnostic test on the herd or flock of origin and on embryo-derived progeny, and the probability of the disease being transferred along with the embryo, an estimation can be made of the risk of allowing an infected but test-negative embryo-derived import to leave a quarantine program.

Estimates of the probability of a particular disease not being transmitted by embryo transfer may be made by examination of the literature to determine the number of experimental transfers which have been made from infected donors to susceptible recipient animals with confidence limits then being determined from scientific tables.

The equation $\beta = [1 - ts/n]^{pn}$, mentioned earlier, which is based on the hypergeometric distribution modified to take into account test sensitivity, can be rearranged (MacDiarmid, 1987) to calculate the minimum prevalence of true infection, p, which must be present in a herd for a given test to identify at least one test-positive animal with a nominated confidence level equal to $(1-\beta_m)$:

$$p = \log \beta_m / n\log (1 - ts/n)$$

In other words, if the test procedure detects no test-positive animals in a sample size t from a herd/flock of size n, then at confidence level $(1-\beta_m)$, we can say that the herd/flock is free of infection or has a prevalence less than p (MacDiarmid, 1987).

Table 13.3 shows how one may calculate the risk of a particular List A disease entering a country through an importation based on an embryo transfer program and a policy of a single test-positive disqualifying the entire shipment. Values for size of herd/flock, test

sensitivity, number of donors, average number of offspring/donor and probability of transmitting disease by embryo transfer are all hypothetical in this example.
In applying the model in practice the variables shown in Table 13.3 are incorporated into a Latin hypercube simulation model as distributions of values, using the PC software program @RISK.

13.5.3 The risk of introducing rabies through the importation of dogs

There has never been a case of rabies recorded in New Zealand. Isolation and stringent quarantine policies have kept the disease from being introduced. Current import requirements restrict entry of dogs to those resident in a very few rabies-free countries.

Table 13.3 Risk of a disease being introduced by an embryo transfer program with a policy of a single test-positive disqualifying the entire shipment

Assumptions: negative test on herd/flock of origin; embryos imported; offspring quarantined; recipients slaughtered; single case disqualifies entire import	
Size of herd/flock of origin,N	300
Number tested,t	300
Sensitivity of test in herd/flock,s	0.9
Nominated confidence level	0.95
Therefore β is	0.05
Maximum prevalence to escape detection,$p=\log\beta/N\log(1\text{-}ts/N)$	0.0043
Number of donors,n	50
Average number of offspring/donor,m	4
Probability of transmitting disease by ET	0.01
Sensitivity of test on progeny	0.9
Proportion of donors that are infected, pD	0.0043
Proportion of donors that are **not** infected, qD	0.9957
Prop. of progeny from infected donors that are infected,pE	0.01
Prop. of progeny from infected donors that are **not** infected,qE	0.99
Proportion of infected progeny which test positive, pC	0.90
Proportion of infected progeny which test negative,qC	0.10
Prob.(0 infected among progeny) = $\{qD+pD[qE]^m\}^n$	0.9915
Prob.(1 or more infected among prog.) = $1-\{qD+pD[qE]^m\}^n$	0.0085
Prob.(0 reactors among progeny) = $\{qD+pD[qE+pE(qC)]^m\}^n$	0.9923
Prob.(1 or more reactors) = $1-\{qD+pD[qE+pE(qC)]^m\}^n$	0.0077
Prob.(0 infected in test-negative group) = $(\{qD+pD[qE]^m\}/\{qD+pD[qE+pEqC]^m\})^n$	0.9992
Prob.(1 or more infected in test negative group) = $\mathbf{1-(\{qD+pD[qE]^m\}/\{qD+pD[qE+pEqC]^m\})^n}$	**0.0008**

However, with a better understanding of the epidemiology of rabies and the efficacy of vaccination, a re-examination of import policies was conducted in 1994. As part of that an assessment was made of the risk of releasing a rabid dog from quarantine under each of a number of import policies based on quarantine periods of different duration, with or without verified vaccination status.

The PC program @RISK was used to construct a Latin hypercube risk assessment model. The unrestricted risk (R) of selecting a rabies-infected animal, without any safeguard being in place, was estimated as:

$$R = (i \times d) / 365$$

where

i = incidence; and

d = incubation period in days.

A triangular distribution was used to estimate d. From an examination of the literature values selected for d were: minimum 10, most likely 56 and maximum 365 days.

An estimate of the range of incidences of rabies in dogs in a number of countries was calculated by dividing the population of dogs in the country by the number of cases of rabies per year (Table 13.4).

Table 13.4 Cases of rabies per year, reported and projected incidence, and the probability that a randomly selected animal will be infected with rabies

Country or city/total number of dogs	Reported cases (minimum)	Most likely number of cases (reported x 1.5)	Maximum number of cases (reported x 5.0)	Risk of selecting an infected animal per million[d]
USA (54.6m dogs)	91[a]	137	455	1.6
Canada (5m dogs)	100	150	500	20
France (9.8m dogs)	38	57	190	3.8
Germany (5m dogs)	192	288	960	38
Philippines (6m dogs)	525	788	2625	86
Lima (0.42m dogs)	3b	1260c	4200	1700

[a] These are the rabies cases in pet dogs, ie, 84% of the reported canine rabies cases

[b] The number of cases fell to this following a vaccination program

[c] The number of cases the year before the vaccination program

[d] Mean risk of selecting an infected animal is mean incidence x mean incubation in days/days in the year

As it is probable that the reported number of cases reported underestimates the real incidence of the disease, an attempt was made to address this by creating a range of incidences. For example, the number of cases of rabies in dogs in the United States in 1988 was 91. In the risk assessment we considered that the 'most likely' number of cases was actually 50% higher than this (137) and had the occurrence of rabies in dogs been grossly underreported, we considered that the actual number could have been five times greater (455). These values were used to describe a triangular distribution used in the model. Table 13.4 shows the mean unrestricted risk of selecting an infected dog. In practice, the simulation model estimated a distribution of values for this risk.

Once the magnitude of the unrestricted risk of introducing a rabies-infected dog has been estimated, the effects of vaccination and quarantine were assessed, again using a range of values (Table 13.5) in a simulation model. The effect of each safeguard is the product of the unrestricted risk and the estimate of failure of the safeguard.

Table 13.5 Probability that safeguards will fail to prevent the introduction of rabies

	Minimum estimate of risk	Most likely estimate of risk	Maximum estimate of risk
Safeguard - vaccination. Probability that vaccination will not protect the dog.	0.01	0.06	0.20
Safeguard - quarantine. Probability that 1 month of quarantine will not detect a dog incubating rabies.	0.47	0.50	0.55
Probability that 4 months of quarantine will not detect a dog incubating rabies.	0.22	0.25	0.28
Probability that 6 months of quarantine will not detect a dog incubating rabies.	0.09	0.11	0.13

The simulation model was run for 5000 iterations. Table 13.6 shows the estimated risks of introducing from the United States a dog incubating rabies following the application of different risk reduction strategies. In 95% of iterations the risk estimate was less than that shown in Table 13.6. The model also generated risk estimates for imports from the other countries listed in Table 13.6, but these will not be reproduced in the present discussion.

On the basis of the results of the simulation model it was concluded that vaccinated dogs imported without prolonged quarantine pose no greater risk of introducing rabies than dogs entering through a 6-month quarantine.

Table 13.6 Estimated risks of introducing from the United States a dog incubating rabies, expressed as the number of dogs per 1 million. Ninety-five percent of the iterations of the @RISK simulation model produced estimates equal to or less than the value shown.

Safeguards	Risk
1 month quarantine	1.92
4 months quarantine	0.95
6 months quarantine	0.42
Vaccinated	0.39
Vaccinated and 1 month quarantine	0.20
Vaccinated and 4 months quarantine	0.097
Vaccinated and 6 months quarantine	0.042

13.5.4 The risk of introducing fish diseases in salmon flesh

Access to New Zealand markets for products derived from wild, ocean-caught Pacific salmon from Canada has been opposed by local salmon farmers and recreational fishers who have expressed serious concerns about the disease risks posed by such importations. These concerns led the New Zealand Ministry of Agriculture and Fisheries to carry out an analysis of the risks of introducing exotic fish diseases through importations of headless, eviscerated, wild, ocean-caught Pacific salmon from Canada (MacDiarmid, 1994). This risk analysis concluded that none of the 23 diseases of salmonids present in North America is likely to be introduced into New Zealand should imports be permitted.

For table fish to serve as a vehicle for the introduction of fish disease, a number of criteria must be met:

- the disease must be present in the waters of origin;
- the disease must be present in the particular fish caught (or the flesh must have become contaminated during processing);
- the pathogen must be present in the imported tissues;
- the diseased flesh must pass inspection and grading procedures;
- the pathogen in the flesh must survive storage and processing and be present at an infectious dose;
- the pathogen must be able to establish infection by the oral route or by the host being bathed in it; and
- scraps of the flesh product must find their way into a susceptible fish host in New Zealand or an infectious dose of pathogen must find its way into contact with a susceptible fish host by some other means.

Taking these factors into consideration, a non-quantitative risk analysis led to the conclusion that of all the exotic diseases present in North American salmonids, furunculosis, caused by the bacterium *Aeromonas salmonicida*, is the disease which would be most likely to be carried in the type of commodity under consideration.

A quantitative risk assessment took into account what is known of the prevalence of *A. salmonicida* in wild, ocean-caught Pacific salmon, the distribution and numbers of *A. salmonicida* found in infected Pacific salmon, the effect of processing on the number of *A. salmonicida* in the tissues of infected fish, the survival of *A. salmonicida* in the environment, the dose of *A. salmonicida* required to infect susceptible fish (of any species), and waste management practices in New Zealand.

The risk assessment concluded that the risk of introducing *A. salmonicida* into New Zealand's farmed, recreational or native fish stocks is extremely remote. For chilled, headless, eviscerated salmon the model estimated that there is a 95% probability that there would be fewer than 1 disease introductions per 10 million tonnes imported. To put this into perspective, the analysis pointed out that the entire annual production of wild, ocean-caught Pacific salmon in British Columbia is no more than 100 000 tonnes.

The analysis recognized that the risks associated with other diseases would be cumulative to the risks posed by *A. salmonicida* and that any risk posed by any one of the other diseases must be added to that posed by furunculosis. However, the analysis also outlined reasons for considering that no disease is more likely to be introduced than *A. salmonicida* and that the cumulative risk of disease introduction is unlikely to be significantly greater than the range of risk estimates described for *A. salmonicida*.

The risk analysis concluded that the overall risk of introducing diseases of salmon through the vehicle of headless, eviscerated, wild, ocean-caught Pacific salmon, appropriately certified by the Canadian government authorities as to origin and grade, is negligible and poses no threat to either New Zealand's wild and farmed salmonid stocks or to non-salmonid fish stocks.

13.6 Concluding remarks

Even in situations where the risk from unrestricted entry can be quantified objectively, and little controversy surrounds the calculation of the extent to which safeguards reduce that risk, it may be difficult to attain agreement on what constitutes an **acceptable risk**. In discussing opposition to proposed changes to Britain's policy of prolonged quarantine of dogs imported from Europe, Wilson (1994) pointed out that the risk of any individual dog imported under the new policy incubating rabies is about 1 in 15 000 000. He compared this to the 1 in 10 000 probability that a large asteroid or comet will collide with the Earth during the next century.

Risk is proportional to the volume of imports. The effect that size of an importation has on risk has been mentioned already. It can be seen that where a policy of excluding only reactor animals is practised, risk increases as either size of a shipment increases or the number of shipments increases.

On the other hand, while a policy of excluding an entire shipment on the basis of even a single reactor results in a reduced risk with larger shipments, an importer could protect his or her investment by splitting a large importation into several smaller ones. While this would reduce the importer's financial risk it would increase the importing country's risk of exposure to exotic disease.

The discipline of quantitative risk analysis, as it applies to the importation of animals and animal products, is still in its infancy and may be regarded with grave suspicion by some stakeholders. For example, one editorial referred to risk analysis as a fad "...related more closely to developing a bureaucratic excuse that few outsiders can fathom than to intelligent decision-making" (Anderson, 1994). Such concerns can only be allayed by practitioners of the discipline striving to harmonize approaches to risk analysis and to standardize terminology.

While this discussion has concentrated on quantitative risk analysis, non-quantitative methods should not be forgotten. Until recently quarantine authorities tended to base decisions almost solely on non-quantitative risk analyses, and these still have a valuable role to play in the routine administration of imports, especially of animal products. Non-quantitative risk analyses can be objective, repeatable and transparent and always take less time, and thus are less expensive, than quantitative analyses. Nevertheless, with increasing frequency quarantine authorities are having to deal with import proposals which require a quantitative approach. While it has been possible in the past for regulators to avoid risk by refusing access, in the post-GATT environment this option is less acceptable and so quarantine authorities around the world are beginning to adopt the discipline of quantitative risk analysis.

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References

Acree, J.A. & Ahl, A.S. (eds), 1991. Proceedings of the international seminar on animal import risk analysis. August 11, 1991, Carlton University, Ottawa, Canada. United States Department of Agriculture, Animal & Plant Health Inspection Service, Hyattsville, Maryland, 64 pp.

Ahl, A.S., Acree, J.A., Gipson, P.S., McDowell, R.M., Miller, L. & McElvaine, M.D., 1993. Standardization of nomenclature for animal health risk analysis. Revue Scientifique et Technique de l'Office International des Epizooties 12: 1045-1053.

Anderson, D.L., 1994. Mother's gooseberry bushes. Live Animal Trade & Transport Magazine VI(4): 2-3.

Harkness, J., 1991. Review of conditions applied to the import of hides and skins into New Zealand. NASS Publication 91-3. Ministry of Agriculture and Fisheries, Wellington.

Kellar, J.A., 1993. The application of risk analysis to international trade in animals and animal products. Revue Scientifique et Technique de l'Office International des Epizooties 12: 1023-1044.

MacDiarmid, S.C., 1987. A theoretical basis for the use of a skin test for brucellosis surveillance in extensively-managed cattle herds. Revue Scientifique et Technique de l'Office International des Epizooties 6: 1029-1035.

MacDiarmid, S.C., 1991. The importation into New Zealand of meat and meat products. A review of the risks to animal health. NASS Publication 91-2. Ministry of Agriculture and Fisheries, Wellington: 168-170.

MacDiarmid, S.C., 1994. The risk of introducing exotic diseases of fish into New Zealand through the importation of ocean-caught Pacific salmon from Canada. Ministry of Agriculture and Fisheries, Wellington, 161 pp.

Marchevsky, N., Held, J.R. & Garcia-Carrillo, C., 1989. Probability of introducing diseases because of false negative test results. American Journal of Epidemiology 130: 611-614.

Morley, R.S. (coordinator), 1993. Risk analysis, animal health and trade. Revue Scientifique et Technique de l'Office International des Epizooties 12. Office International des Epizooties, Paris, 434 pp.

Wilson, A.J., 1994. Rabies policy. [Correspondence]. Veterinary Record 135: 95-95.

14

Examples of integrated information systems for decision making at farm and national level

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Objectives

From this chapter the reader should gain knowledge of:

- the state-of-the-art with respect to computerized decision support systems in animal health management

Various examples are described and illustrated at both farm and national level.

14.1 Introduction

Computers are valuable tools for epidemiological investigation and for management of animal health services at both farm and national level. The nature of information systems is continuing to evolve rapidly as the mobility and capacity of the computer hardware becomes greater and greater, and as new forms of software become readily accessible. Earlier concepts of the objectives of information management were embodied in names such as 'databank' and 'registry'. The analysis of data was handled quite separately from entry and storage, frequently not even on the same computer.

Since then the conceptual framework for information management has matured (Thrusfield, 1983; 1986), and the capability to handle more powerful and especially more integrated information management systems has grown and changed in the light of experience. Currently, information management efforts are directed towards **'decision support'**. The two key concepts in this approach are that the focus is on the decision makers (at both policy and implementation levels) rather than on the system itself, and that as far as possible the components of the decision support system are seamlessly integrated so that a single interface is used to access all features of the system without regard to which component of the system is actually providing the answers.

In this chapter this trend is illustrated with examples from national disease control and from health management systems at farm level. EpiMAN is a decision support system for control of major diseases which require national control or eradication procedures. The first implementation of the approach has been for exotic disease control. The system incorporates a core database with links to a geographic information system (GIS), so that all information about livestock herds and disease occurrence can be linked directly back to the farm location. Expert systems process incoming data immediately and guide outbreak managers on priorities for allocating personnel. Other components of the expert system answer technical questions on demand. Simulation models incorporated into the system predict both the short-term consequences of individual outbreaks as sources of infection, and the longer-term merits of alternative control policies which might be under consideration. An 'epidemiologist's workbench' gives the epidemiologist access to both standard menu-selected reports on demand and the capacity to formulate advanced analyses using built-in software. The system is totally mobile, and can be set up anywhere in the country. The approach embodied in EpiMAN is progressively being extended to endemic disease control programs, other exotic diseases and quality assurance procedures such as chemical residue control. The nature of EpiMAN makes it ideally suited for use as a training tool, as well as an operational tool.

A similar approach is being adopted at farm level. PigCHAMP was developed at the University of Minnesota as a records analysis program for pig herds, and is now being expanded to incorporate farm financial data, abattoir information, expert systems and simulation models. Modules originating at different research centres can be incorporated into the total system, and the user can choose which components to pay for and use, according to need. DairyMAN is an equivalent system for dairy herds developed at Massey University, which is being enhanced with a whole farm simulation model and with expert systems. It is also integrated with the national dairy herd improvement system.

These examples are used to illustrate the nature and value of decision support systems.

14.2 Decision support systems

Decision support systems (DSS) are interactive computer-based systems that help decision makers utilize data and models to solve unstructured problems (Sprague & Carlson, 1982). They exhibit the following characteristics:

- they tend to be aimed at less well-structured, underspecified problems;
- they combine the use of models and analytic techniques with traditional data access and retrieval functions;
- they typically focus on features that make them easy to use by non-computer people in an interactive mode; and
- they emphasize flexibility and adaptability to accommodate changes in the environment and decision-making approach of the user.

The purpose of a DSS is to provide a set of tools to help in the interpretation of data. The DSS should give decision makers an appreciation of the risks implicit in particular decisions, and the factors which can be varied to modify those risks. One approach is to use an expert system with a database management system. Individual decision support systems can comprise part of an overall national animal health information system (Morris, 1991).

An ideal application area for DSS in animal health is in emergency response systems, where typically decision makers have to cope with large volumes of diverse and often imperfect data, inadequate time and resources are available to devote to complex problemsolving, and the outcomes of decisions can have far-reaching consequences. Berke & Stubbs (1989) present a thorough argument in favour of DSS for hurricane mitigation planning. Successful control and eradication of a Foot-and-Mouth Disease (FMD) epidemic is contingent on the rapid identification and elimination of all virus sources. This involves an understanding of the dynamics of the disease, combined with adequate procedures that identify, record and deal with all events that may contribute to further spread of the disease. The EpiMAN project was initiated to develop a DSS to be used by the Ministry of Agriculture and Fisheries (MAF) should an FMD outbreak ever occur in New Zealand.

14.3 Description of EpiMAN

EpiMAN is a system for national control of major animal diseases, initially concentrating on FMD. It was developed in New Zealand as part of national preparedness for any future outbreak of this major exotic disease, but is now under consideration for adoption in a number of other countries. The system runs on a pair of linked Sun workstations (database server and graphics workstation), to which personal computers are networked. Replaceable hard disk cartridges are used to allow rapid switching to different diseases and areas. Fast printing of colour maps and of reports is provided. The whole system is designed for easy and rapid transport by air or land, and immediate service at the operational site.

A key function of the DSS is management of the large volume of data typically generated during an emergency. A computerized database management system is ideally suited to such a task. The need to have a 'bird's eye view' of the situation, the need for presentation of status reports in formats that are easy to comprehend, and the need to understand the dynamics of the disease in a spatial context led to the evaluation and subsequent adoption of a geographic information system (GIS) in EpiMAN. It is noteworthy that an analysis of FMD outbreaks in unvaccinated populations in Europe from 1965 to 1982 (Lorenz, 1986) showed that although the median outbreak size was 29 farms, the mean size was 1048, because 30% of the outbreaks were massive. An important objective of EpiMAN is to make massive outbreaks much less likely.

Computer simulation models are programs which seek to represent the dynamics of real-world systems. Models can be linked to information systems to provide procedures for the evaluation of management options based on an analysis of the current situation (Marsh, 1986; Jalvingh, 1993). In this manner, the information collection system serves to provide parameter estimates for the model. These estimates are updated as new information is acquired, and the model can be re-run to assess the new situation.

New Zealand has never had an outbreak of FMD and hence, there are very few veterinarians in the country with the experience or knowledge to fully understand the epidemiology of the disease. An FMD epidemic would place a severe demand on qualified manpower resources to run all facets of the Emergency Headquarters procedures. Expert systems, which can emulate aspects of human reasoning, have an obvious role to play in interpreting epidemic data and aiding in the decision-making process.

Figure 14.1 shows the structure of EpiMAN. The core of the system is a comprehensive database, consisting of spatial data, textual data and epidemiological knowledge of FMD (contained within the FMD models and expert systems). The epidemic-related tabular data and farm profile information associated with farms in the infected area is stored in the database management system.
Associated with this are the digital maps of the infected area which are stored and managed by the GIS. The models of FMD spread and the expert systems operate on these spatial and textual datasets, using a set of epidemiological parameters which describe aspects of the behaviour of FMD. Initially these variables have a set of default values, but are modified through immediate statistical analyses of the spatial and temporal patterns of the particular epidemic. Details of these various components are discussed below.

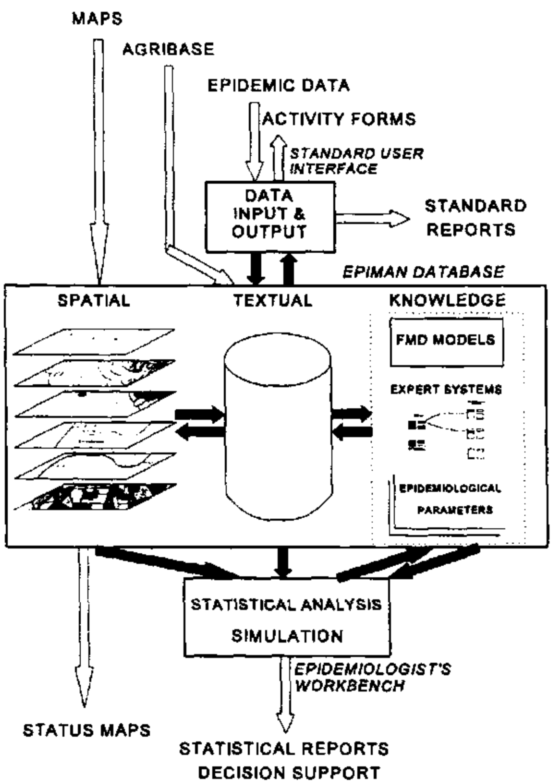

Figure 14.1 The structure of EpiMAN

14.3.1 Core textual database

The database is capable of containing information on all livestock units in the outbreak zones. This is however not essential for the operation of the system, which can work with much simpler data such as grid locations of affected and at-risk farms, but extends the power of the system to enable the assessment of risk factors and the prediction of disease spread. To facilitate this, consideration is being given to creation of a national agricultural index system (Agribase) that will contain basic farm profile information on every commercial farm in the country. Each farm will have a unique farm identification number, being the key field throughout the EpiMAN system, and providing the link between the GIS and the database management system.
The recent development of low-cost hand-held geopositioners intended for navigation offers another attractively simple way of dealing with location information. These allow the user to stand at an outbreak site and instantly determine the exact location by satellite telemetry

(at no cost). This information can then be fed into the database where it is immediately linked to its map location, removing the need for locating farms on paper maps to enter their geographical locations.

14.3.2 Spatial database

EpiMAN employs the Arc/Info[1] GIS operating on a UNIX workstation to manage the spatial aspects of the system. A range of graphical and other reports can be provided from the GIS. Various overview maps can be generated, showing the location of all infected and at-risk properties - some suitable for use by the Chief Veterinary Officer and the media, others intended for use in the Emergency Headquarters for assignment of duties. Local maps can also be produced as a result of the risk evaluation by the expert system, showing farms to be visited plus surrounding properties.

Although the use of individual property boundary information gives the system maximum power to support decision making, various less detailed methods can be used to come close to this level of detail. The nature of the GIS means that provided each map coverage is 'registered' through a reference point, maps of different types can be overlaid on each other for visual or analytical assessment. For example, a standard paper map can be optically scanned and presented on the screen with outbreak and other data visually superimposed on it so that disease data can be related to geographical features in a familiar way. Thus advanced digital map data are not essential. Where digital map data are available, these can be used to recreate a 3-dimensional image of the land surface in the area, again allowing these data to be displayed in relation to outbreak information.

14.3.3 FMD models

On-farm virus production model

When a new infected premises is discovered, there is an urgent need to evaluate what opportunities there have been for further spread of disease from the moment of virus arrival on the property to the time of diagnosis. The probability of spread for each opportunity is directly proportional to the build-up of infection on the farm and the consequent release of virus into the environment.

A Monte Carlo simulation model that resimulates the sequence of events on the farm, and quantifies the degree of environmental excretion of FMD virus has been developed and incorporated into the EpiMAN system. The model simulates the spread of infection among animals of the first species infected on the farm, and then to other species on the same farm, reports the numbers of animals infected/clinical/carriers on a daily basis, and computes the total quantity of FMD virus liberated into the atmosphere on a daily basis; and in the case of dairy farms, the daily concentration of FMD virus expected in the farm milk supply.

Meteorological spread model

The on-farm model simulates the release of FMD virus into the atmosphere, as discussed above.

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[1]Environmental Systems Research Institute, Redlands, California, USA.

The meteorological model is then run, using standard methods to produce virus concentrations in each of a large square of geographical blocks or cells surrounding the source. The concentration of FMD virus for each cell is accumulated for each day, as it is assumed that if there is insufficient virus to infect an animal over a 24-hour period, the virus will be inactivated. The grid concentrations are then processed by the GIS to identify properties at risk.

Inter-farm spread model

A true DSS should allow a manager to conduct a series of **'what-if' scenarios** to investigate the likely consequences of major policy options. In terms of managing an FMD epidemic using a stamping-out philosophy, strategies include changing the size of the infected area, adjusting the size of the patrol zone (standstill zone) around infected premises, instigating pre-emptive slaughter (dangerous contact slaughter) and implementing a ring vaccination buffer. In order to test these major control options adequately, a spatial simulation model has been developed that operates on the actual geographical data.

Three infection processes are modelled - local spread, movement related spread and recrudescence. To investigate alternative control options, the user can alter the patrol zones, change the size of the infected area, instigate a dangerous contact slaughter policy and create a vaccination buffer. The entire epidemic can be resimulated with the alternative policies in operation, or the user has the opportunity to implement changes during a particular simulation run. If the control procedures are adequate, the disease is eradicated. If not, the dissemination rate remains high and the disease eventually becomes endemic. Outputs of the model are the numbers of farms diagnosed per day (or per week), the dissemination rate, the length of the epidemic, and the number of farms to be patrolled on each day throughout the epidemic.

14.3.4 Expert systems

Development of a system to assign priorities to tracing movements

One of the bottlenecks identified in the operation of the Emergency Headquarters was the follow-up work associated with traces involving movements of people, animals or materials onto or off infected premises in the period leading up to diagnosis. A recent study in New Zealand has shown that the number of traces which would need to be assessed per farm would be over 50. In a large epidemic involving multiple infected premises being identified daily, such as the UK 1967/68 epidemic where there were 80 new farms identified as infected per day at the height of the emergency (Northumberland Report, Part I, 1968), the number of traces to investigate would quickly place an overwhelming demand on manpower resources.

Investigation of traces involves first establishing whether or not there is a risk of FMD having been transferred with the particular movement. An expert system assigns risk ratings varying from very high to nil. The assignment of risk ratings is based on a set of decision rules which have been incorporated into the expert system. This process identifies 'at-risk' properties and potentially contaminated equipment and vehicles.

Rating of at-risk farms and patrol requirements

There are numerous circumstances that place farms at risk of contracting FMD. These include being involved in a trace from an infected farm, proximity to an infected farm, being exposed to an airborne plume of FMD virus and being on a dairy tanker route from an infected farm to the factory. An essential part of managing an emergency is ensuring all events or circumstances that place properties at risk are investigated and that these farms are monitored according to the degree of risk. An expert system has been developed to conduct these tasks.

There are several components to this system. The first stage records the specific event or situation that places a farm at risk. Each of these episodes is recorded as an episode in the database management system. For each episode, a risk rating is applied, the earliest date at which clinical signs can be expected is derived and the date by which the episode can be discounted if no clinical signs have appeared computed. A summary entry is then recorded for each property into an At-Risk file, where a combined risk value is derived for the farm, the earliest date by which clinical signs can be expected recorded, the date at which it can be recommended that the farm be removed from the patrol list and the optimum patrol frequency entered.

Technical information database

During an FMD emergency, the range of possible scenarios and the complexity of interacting factors invariably lead managers to have to make decisions regarding the eradication of the disease, where the circumstances of the particular farm are atypical. In these situations, there will inevitably be additional technical information on some aspect of FMD that would aid the decision maker. Although there is extensive literature on the epidemiology of FMD, a ready source of technical information on FMD at the Emergency Headquarters would be a real help. This perceived need has led to the development of a knowledge-based technical reference system on the epidemiology of FMD. The system is known as FMDHELP and has been developed using the expert system shell *Nexpert Object*. Basically the user selects one of the broad categories of subjects relating to FMD for which technical information is desired. The user is then presented with a list of subheadings within that subject to choose from. On selection of one of these, a file of specific information is shown on screen, which the user can scroll through at leisure. The system then returns the user to the front menu containing the major categories.

14.3.5 Epidemiologist's workbench

At the peak of an exotic disease emergency it would be difficult to spend time designing and conducting analyses to evaluate the effectiveness of the eradication effort. Hence EpiMAN contains a set of tools which have been designed in advance either to conduct standard analyses or to carry out particular forms of analysis on the data files, with specific details being provided by the epidemiologist at the time. All of these procedures will be accessible through a menu system, described as the workbench. They will be carried out by a statistical package which has advanced analytical and graphing capabilities.

For example, the system will be able to automatically build a graphical network on request to represent its best assessment of the epidemiological links between the various infected premises detected to date, and will reassess the network each time a new infected premises is found. The shape of the epidemic curve and the estimated dissemination rate will be calculated, and a forward extrapolation will be made from this. A series of detailed indicators will also be calculated to assess changes in the mechanisms of spread which appear to be operating as the outbreak develops, and to evaluate the extent to which new infected prem-ises are failing to be predicted in advance by earlier 'at risk' lists, which would indicate that unexpected transmission patterns are occurring. Survival analysis and proportional hazards regression will be used to assess factors influencing the development of local clusters of infected premises.

14.3.6 Economics module

EpiMAN is being extended for use in Europe, as the system EpiMAN (EU). As part of this development an economic module is added to the system (Jalvingh *et al.*, 1995). This will take data from the operational data management system and use them to conduct economic analyses of alternative policies at national and European Union level. This will be a macroeconomic analysis system and integrated with the inter-farm spread model.

14.4 Extension to other national animal health programs

A substantial amount of work was required during the initial design of EpiMAN to prototype various alternatives and choose how best to develop an integrated system. Two of the major design criteria were that the system be capable of operating on various hardware platforms, and that it be adaptable to other tasks beyond FMD.

It is proposed to extend the exotic disease capabilities of EpiMAN beyond vesicular diseases to cover various groups of diseases which share common features, so that there will eventually be up to five variants of EpiMAN to cover the range of epidemic diseases. Many of the features will be common, but specialized aspects for rabies or insect-borne diseases can be handled by disease-specific modules which would replace the vesicular disease module when required.

The system can also be adapted for use in control of endemic diseases. In New Zealand tuberculosis (TB) has become established in the Australian brush-tailed possum, and this means that control of the disease involves wildlife as well as domestic cattle and deer. A version of EpiMAN is being designed to use the geographical capabilities of the system to manage the wildlife and domestic animal aspects of tuberculosis jointly, using vegetation and landform information which determine possum ecology to handle possum control aspects, while in another overlay domestic stock TB control is managed within property boundaries, taking into account stock movement information.

A computer simulation model of TB has been developed in which the epidemiology of the disease is simulated on the actual geography of the area, at micro-, meso- and macro-scale, using a three-tiered modelling approach. The model uses parameter estimates derived from detailed epidemiological studies currently being conducted on the disease (Pfeiffer & Morris, 1991).

The completed system will be able to conduct management procedures and analyses comparable to those described for FMD, but targeted to the longer-term needs of an endemic disease control program. Work on the various constituent parts of the system is under way. Because the control effort for TB takes place through local area disease control managers, it is envisaged that the components of the system required for local control program manage ment will be made available at district offices, including the reduced form of Arc/Info called ArcView, which enables simpler GIS procedures to be carried out purely by menu selection, on a PC.

Because of its large international trade in animal products, New Zealand places great importance on its international standing as 'clean and green', and hence on the maintenance of quality assurance procedures for products leaving the country. Another capability of EpiMAN is to manage data concerning such quality assurance procedures as chemical residue testing and meat inspection findings, linking this back to the farm and area of origin so that sound claims can be made about the status of product going to various markets. Development of this aspect of the system is envisaged for the near future.

Because many of the data are common to these various systems and removable disk cartridges are being used for system-specific data, the same equipment and purchased software can be applied to widely different problems over the same period, ensuring that users are familiar with it in various applications. It will also make it possible to have the system permanently ready to handle an exotic disease emergency immediately, should one arise.

14.5 Decision support systems for farm use

Herd information systems are currently expanding in scope to become decision support systems, much as national disease information systems are evolving in the same direction. In both cases this results in part from the development of an increasing range of computer programs which all use the same data. There is pressure from users to avoid re-entry of the same data, and both hardware and software developments are making this easier to achieve. In technical terms, this linking of software and the capacity for different programs to access the same data file is called **'seamless integration'**. With appropriate care separate pieces of software can be integrated by sharing a common interface and menu system, so that a single main menu gives access to alternative programs, and transfer of data from one program to the other is transparent to the user. Both may make use of a single data file, as long as the programs respect the rules concerning file opening and closing, and especially obey the same rules concerning file modification. Increasingly, software is moving towards complying with the Common User Access rules, which means that all programs look and act in similar and consistent ways. Two examples will be given of herd systems which are developing the features of decision support systems.

14.5.1 Pig herd decision support

The pig records system PigCHAMP was developed in the US at the University of Minnesota in the 1980s, and has now become the most widely used system of its kind in the world. Initially it dealt only with the breeding herd, but it has since expanded to cover the growing herd. Moreover, an overall financial analysis of the herd was included, and an interface to a farm accounting package so that accounting data can be shared between the programs. A comprehensive database evaluation module within PigCHAMP allows the user to go beyond predefined reports to produce a variety of types of graphical and text reports on over 200 variables, with user-selected inclusion and exclusion criteria. In this way great flexibility to produce epidemiologically valid reports can be achieved without sacrificing simplicity of access.

There is also a direct interface through a PigCHAMP menu item to a simulation model of the pig breeding enterprise, PigORACLE. This allows current herd productivity data and herd composition to be used to create a forward prediction for the next six years of physical and financial performance of the herd, and then to vary the price and performance assumptions and evaluate the sensitivity of performance to these changes. Equivalent models for the growing herd have become available in recent years (Black & Barron, 1988), and there are plans to link one or more of these growth models to PigCHAMP to allow evaluations of feed formulation and management to be conducted within the overall herd information system. These models of growth are technically very complex, and make available to the user a synthesis of experimental data and field experience in the form of a predictive model for the growing pig.

Expert systems are also being added to the total system at present. CHESS (Computerized Herd Evaluation System for Sows) assesses the performance of a single breeding herd in relation to its own previous performance and in relation to performance of a peer group of herds over a single time period and over a series of time periods. It reports back likely sources of suboptimal performance, which can then be investigated further (Huirne *et al.*, 1992). It is being interfaced directly to PigCHAMP, so that CHESS evaluations can be run as a PigCHAMP menu selection, using peer group data for a chosen 'comparison group' of herds. PigCHAMP is able to do comparative analyses on up to 200 herds, which will generate the peer group data for such analyses. If reproductive performance in the herd is found to be suboptimal, then a second expert system PigFIX (Fertility Investigation eXpert) is being developed (Wongnarkpet *et al.*, 1993) to automatically run and analyse various reproductive reports available within PigCHAMP. It will then guide the user to issues which deserve priority in herd investigations. A third system, TACT (TActics and ConTrol) simulates herd production, reproduction and replacement policy, and recommends an overall policy for the herd dependent on its performance, and will assess what action is economically optimal for individual culling decisions (Jalvingh, 1993).

The system is also being extended to incorporate other data. For example, both carcass data and slaughter inspection data can now be returned to farm files electronically, and used in a comparative evaluation of occurrence of lesions in the particular herd versus its peers. Other complementary modules of a similar nature are planned for the future.

Electronic identification by transponder is gradually emerging as a practical technology for animal recognition, and is likely to become widely used over the next decade. Already in use and likely to become more widely accepted is the use of electronic identification in combination with hand-held data loggers/computers, in some cases with FM radio exchange of data with the computer which is storing the primary records, and which is located in the farm office. In this way seamless integration can occur throughout the process from animal recognition to report production and evaluation.

14.5.2 Dairy herd decision support

A similar process is occurring in dairy herds. In North America programs such as Dairy CHAMP are developing the same degree of functional integration, and in the Netherlands advanced economic models are being developed to simulate and optimize farm- and cow-specific insemination and replacement decisions (Jalvingh, 1993; Houben, 1995) which can be integrated into the system.

In New Zealand and Australia DairyMAN is designed to provide comprehensive support for pasture-based dairy herds. DairyMAN contains a core information system which handles production, reproduction and health data, and analyses these in both report and graphical formats. The system is now fully integrated with the national dairy herd recording and artificial insemination system, so that data can be downloaded from the national database to create (and in most cases maintain) the farm database. Plans are in hand to upload data from the farm to the national database as well. Work has commenced on an expert system DairyFIX (McKay *et al.*, 1988) which will evaluate herd performance in much the same way as PigFIX will do for pig herds. In other places expert systems are already employed for purposes such as analysis of lactation curves (Fourdraine *et al.*, 1992).

There are special problems with modelling pasture-based livestock production, which make development of a model of a grazing farm much more difficult than one of a housed enterprise such as a pig farm. However, a model, FarmORACLE, has been developed which simulates a farm on a geographical surface comprising a paddock layout specified by the user, together with agronomic details for each paddock. All major grazing species in New Zealand can be allowed for, and the dairy herd which is simulated can be the one stored in DairyMAN. Farm management can be simulated with appropriate management decisions and paddock rotations, with output consisting of financial and physical performance indices (Butler & Morris, 1993).

As milking parlour management and data gathering become increasingly automated, more and more use is being made of integration between different methods of measurement of production, mastitis, oestrus activity and other variables of interest to the farmer. Because of the large flow of information which arises from such systems and the difficulty in discriminating abnormal from normal patterns, such techniques as **neural net analysis** are being used in an effort to distill the data down into useful management aids (Nielen, 1994).

14.6 Concluding remarks

Developments in hardware and software design over the past two decades have laid the foundations for information management in animal health to move gradually from what can now be seen as relatively primitive beginnings to tightly **integrated systems** which provide very powerful support for management, evaluation of options and decision making in both national disease control programs and herd management systems. In many ways these represent the embodiment of the current state of epidemiological thinking in the form of integrated processing and analysis systems which use the techniques of epidemiology and economics within practical management systems. In this way current epidemiological and economic thinking becomes accessible to decision makers without the need for them to have direct involvement in determining how the data are analysed and presented to them.

References

Berke, P. & Stubbs, N., 1989. Automated decision support systems for hurricane mitigation planning. Simulation 53: 101-109.

Black, J.L. & Barron, A., 1988. Application of the AUSPIG package for the management of pigs. Proceedings Australian Farm Management Society 15: 5-1 to 5-10.

Butler, B.M. & Morris, R.S., 1993. FarmORACLE: A software package for simulating management of a grazing farm. Massey University, Palmerston North.

Fourdraine, R.H., Tomaszewski, M.A. & Cannon, T.J., 1992. Dairy herd lactation expert system, a program to analyze and evaluate lactation curves. In Prospects for Automatic Milking: 331-337, Pudoc Publishers, Wageningen.

Houben, E.H.P., 1995. Economic optimization of decisions with respect to dairy cow health management. PhD-Thesis, Department of Farm Management, Wageningen Agricultural University, Wageningen, 146 pp.

Huirne, R.B.M., Dijkhuizen, A.A., Renkema, J.A. & Van Beek, P., 1992. Computerized analysis of individual sow-herd performance. American Journal of Agricultural Economics 74: 388-399.

Jalvingh, A.W., 1993. Dynamic livestock modelling for on-farm decision support. PhD-Thesis, Department of Farm Management and Department of Animal Breeding, Wageningen Agricultural University, Wageningen, 164 pp.

Jalvingh, A.W., Nielen, M., Dijkhuizen, A.A. & Morris, R.S., 1995. Computerized decision support system for contagious disease control. Pig News and Information 16: 9N-12N.

Lorenz, R.J., 1986. Economic evaluation of the foot-and-mouth disease vaccination programme in the Federal Republic of Germany. Report, Federal Research Centre for Virus Diseases of Animals, Tubingen, FRG, July 1986.

Marsh, W.E., 1986. Economic decision making on health and management in livestock herds: examining complex problems through computer simulation. PhD-Thesis, University of Minnesota, 304 pp.

McKay, B., McCallum, S. & Morris, R.S., 1988. An expert system for diagnosing reproductive problems in seasonal dairy herds. Proceedings of the Fifth International Symposium on Veterinary Epidemiology and Economics, Copenhagen: 480-482.

Morris, R.S., 1991. Information systems for animal health: objectives and components. Revue Scientifique et Technique de l'Office International des Epizooties 10: 13-23.

Nielen, M., 1994. Detection of bovine mastitis based on milking parlour data. PhD-thesis, Department of Herd Health and Reproduction, Utrecht University, Utrecht, 165 pp.

Northumberland Report, Part 1, 1968. Report of the committee of inquiry on foot-and-mouth disease 1968, Part One. Her Majesty's Stationary Office, London.

Pfeiffer, D.U. & Morris, R.S., 1991. A longitudinal study of bovine tuberculosis in possums and cattle. Proceedings of Symposium on Tuberculosis, Palmerston North: 17-39. Foundation for Continuing Education of the New Zealand Veterinary Association.

Sprague, R.H. & Carlson, E.D., 1982. Building effective decision support systems. Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 329 pp.

Thrusfield, M.V., 1983. Application of computer technology to the collection, analysis and use of veterinary data. Veterinary Record 112: 538-543.

Thrusfield, M., 1986. Veterinary epidemiology. Butterworths, London, 280 pp.

Wongnarkpet, S., Morris, R.S. & Stern, M., 1993. PigFIX: A software package for analysing pig reproductive records. Massey University, Palmerston North.

15

Profitability of herd health control and management information systems under field conditions

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Objectives

From this chapter the reader should gain knowledge of:

- basic requirements for an economic analysis of field data on animal health and management support
- the profitability of herd health control programs
- the profitability of management information systems

15.1 Introduction

As also indicated in Chapter 2, veterinary services to individual farms are increasingly changing from the so-called first-aid practice or fire-brigade approach into planned prevention and control programs. For a sound economic analysis of such programs, data from both the 'with' and 'without' situations should be available (Dijkhuizen, 1992). This may be realized 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, ie, $(P_a\text{-}P_b)$ - $(C_a\text{-}C_b)$, especially when particular herds with obvious health and management problems take part in the program. Collection of data in the 'without' situation should be done concisely, however. Otherwise an interference with the program may occur, leading to an underestimation of the program effects.

In this chapter two field trials in the area of animal health and management support that were designed and analysed along these lines are presented and discussed. The first application includes a 2-year herd health and management program in dairy cattle, carried out on 30 program and 31 control farms (Sol *et al.*, 1984). The second one focuses on the so-called management information systems (MIS) on pig farms, designed to support the farmer's management by providing information on the performances of single animals and the herd as a whole (Verstegen *et al.*, 1995).

15.2 Herd health and management control in dairy cattle

In the Netherlands, a 2-year dairy herd health and management program was carried out from 1974/75 to 1976/77, including 30 program and 31 control farms. The program was a joint experiment of the Animal Health Service and the Agricultural Extension Service in the province of Overijssel. Each of the 37 extension workers was asked to select three dairy farms with at least forty cows and without specific herd health problems. Further requirements were a modern housing system for cows and youngstock, artificial insemination, milk recording, roughage analysis and a reasonable economic and herd health recording system. The program and control farms were randomly chosen from each set of three, the third farm being excluded from the trial. Seven program and six control farms were excluded from the initial program evaluation because they did not have the necessary economic data at the time of analysis.

The year 1974/75 was used as a base year in which relevant data were collected from both groups before the program started. During the program years (1975/76 and 1976/77), the program farms were visited every six weeks by the veterinarian of the Animal Health Service, the local veterinarian and the local extension worker. These visits primarily focused on reproduction, udder health, foot care, nutrition, cow culling, grassland exploitation and economic results. The control farms were visited twice a year, only to collect the necessary data.

Table 15.1 Comparison of program and control farms before and during the experiment

	Situation 'before' (1974/75)			Changes during program (1976/77 - 1974/75)		
	30P	31C	P-C	30P	31C	P-C
Labour equivalents	1.7	1.6	0.1	-0.1	0.0	-0.1
Grassland area (ha)	31.1	24.7	6.4*	0.3	2.3	-2.0
Dairy cows (no)	69.3	60.9	8.4*	4.7	6.6	-1.9
Fertilizer (kg N/ha)	300	351	-51	42	-24	66*
Milk per cow (kg)	5121	5123	-2	524	390	134
Calving interval (d)	378	376	2	-5.3	3.3	-8.6*
Cell count (x1000/ml)	240	330	-90	-20	20	-40
Total culling rate (%)	21.4	18.7	2.7	0.0	7.1	-7.1*
for reasons of:						
- health/fertility probl.	12.6	10.6	2.0	0.1	5.9	-5.8*
Revenues (US$/cow)	1740	1768	-28	452	385	67
Feed cost (US$/cow)	569	576	-7	198	227	-29
Margin (US$/cow)	1171	1193	-23	256	158	98

* $p < 0.05$

Table 15.1 shows a comparison between the program and control group before and after two years of program application. In the preparatory year (1974/75), the groups showed no large differences. The farms of the program group were slightly larger (hectares of grassland and number of cows) and applied somewhat more nitrogen per hectare. Milk production per cow and health and fertility parameters (including culling data) did not differ between the groups, nor did the costs and returns per cow. The effects of the program were measured by comparing both groups for the changes in the various parameters per farm during the two successive years of program application. Neither group showed much difference in the development of farm structure (labour force, herd size, grassland area), although the program group increased nitrogen fertilization, compared with the control group. Statistically significant effects were found, regarding both calving interval and replacement rate of cows because of ill health and reproductive failure. Regarding udder health (ie, cell count) no significant effect was found. The average increase in the margin of revenues over feed cost per cow turned out to be US$256 in the program group, which is US$98 more than in the control group. Additional - veterinary - costs were estimated to average US$20 at the most, indicating this herd health program to be a sound investment.
From both the farmers' and veterinarians' point of view it is also important to know whether or not such programs should be applied on a more than temporary basis. From these farms, therefore, data were gathered until ten years after participating in the program experiment to see whether the initial effect on income had increased, decreased or remained the same. The necessary data were not available on all 61 farms. Therefore, two new groups were formed, consisting of 15 program farms and 20 control farms respectively. Since the initial and new groups differed in number, the short-term program effects were also re-evaluated. Results are summarized in Table 15.2.

Table 15.2 Margin over feed cost per cow per year (US$) on the program (P) and control (C) farms

	Initial groups			New groups		
	30P	**31C**	**P-C**	**15P**	**20C**	**P-C**
1974/75	1170	1193	-23	1156	1191	-35
1976/77 - 1974/75	256	158	98*	232	167	65
1976/77	1426	1351	75	1388	1358	30
1980/81 - 1976/77				235	414	-179*
1980/81				1623	1772	-149*
1985/86 - 1980/81				599	575	24
1985/86				2222	2347	-125

* $p < 0.05$

During the years of program application (1975/76 to 1976/77) margin over feed cost per cow in the initial groups increased significantly more (US$98) on the program farms than on the control farms, as also indicated before in Table 15.1. In the new groups the short-term program effect was smaller (US$65), and not statistically significant, but showed the same tendency. In the first few years after the program had finished (1976/77 to 1980/81), margin over feed cost per cow increased significantly more (US$179) on the control farms than on the program farms, as a result of both higher milk production and lower feed costs. In the period 1980/81 to 1985/86 the increase in income for both groups was almost the same, ie, between US$575 and US$600 per cow. So, the initial increase in income soon had disappeared after the program had been finished. Such an outcome is not totally unexpected, but - at least beforehand - opinions often differ on this issue. Farmers' decisions, however, have to be taken under continuously-changing price and production conditions. In such dynamic circumstances, therefore, it seems to be profitable to apply herd health and management programs on farms on a more than temporary basis.

15.3 Management information systems in pigs

A longitudinal survey was carried on 71 pig farms in 1992, about 10 years after the first introduction of MIS. All farmers already participated in a socio-economic survey in 1983, henceforth referred to as the 1983 survey. In the 1983 survey, various sociological, technical and economic data of the farms were recorded. Very few farmers made use of MIS at that time, which means that the 1983 data could very well serve as pretest data. In the 1992 survey, data on MIS use and technical production data of the entire period in between the two surveys (1983 to 1992) were collected and formed a unique **panel data** set. In this period, some farmers started to use MIS while others did not.

The objective of the 1983 survey was to relate farmers' characteristics to their production performance. The survey was conducted by means of a questionnaire that was distributed by farm advisers. The research population of the 1983 survey was selected using the following three criteria: (1) the pig farms should include sows as well as fattening pigs, (2) the pig farms should be located in the operating area of the state advisory service, and (3) the pig farmers should be a member of the state advisory service during the entire year of 1982. An important consequence of this last criterion was that all farmers made use of the central Herd Record System which was maintained by the advisory service. This means that all selected farmers received basic information about their farm performance. Hence, farmers with only manual record keeping practices or farmers with no record keeping at all were excluded. The only criteria in the 1992 survey were that: (1) the participants also participated in the 1983 survey, and (2) they still operate a pig farm.

The objective of the evaluation study was to evaluate the effect of MIS on the average number of piglets per sow per year. The panel data were statistically analysed through analysis of variance procedures. Hypotheses about factors that may interfere with the effect of MIS on farm results led to the initial formulation of the statistical model described below. With this model, the annual observations of the parameter **'number of piglets per sow per year'** over the period 1982 to 1991 are explained. The great advantage of having panel data is that effects can be estimated within farms. In this way, distorting effects (such as management quality and motivational aspects of the farmers) can be excluded by inserting a FARM effect into the statistical model. In regression terms, this can be regarded as having one dummy variable for each individual farm (except for the last farm because this farm is already defined by the n-1 other dummy variables). The advantage of having multiple time series is that year effects can be estimated across farms. The process of MIS installation, data entry, learning and, finally, use of its information in farm management takes time and delays the benefits coming from MIS. Including this starting period in the estimation of MIS effects would cause an underestimation of the effect. Therefore, a dummy variable 'First Year Adjustment' (FYA) was defined. The variable FYA corrects the MIS effect for starting problems and for not having MIS during the entire year of adoption. For example, when a farmer starts using MIS in November 1984, an effect of MIS on the 1984 parameter 'number of piglets per sow per year in 1984' can hardly be expected. To estimate the MIS effect, a dummy variable MIS was added to the model and so was a FARM x MIS interaction. This interaction accounts for differences in MIS effects among farms. It was hypothesized that the value of information and thus the value of MIS depends on the information that is already available to the user. For example, farmers with a tradition of intensive recording of sow data are likely to receive less added value of MIS than farmers who obtain more detailed information than before MIS use. It was also hypothesized that there exists a FARM x FYA interaction indicating that some farmers have fewer problems starting to use MIS than others. This interaction was not significant and was removed from the final model. Eventually the following model was estimated:

$$Y_{ijkl} = \underset{(p\leq 0.001)}{YEAR_i} + \underset{(p\leq 0.001)}{FARM_j} + \underset{(p=0.09)}{FYA_k} + \underset{(p=0.08)}{MIS_l} + \underset{(p\leq 0.001)}{FARM \times MIS_{jl}} + e_{ijkl}$$

where

Y	=	piglets per sow per year;
$YEAR_i$	=	year effect (i=1982, 1983...., 1990, 1991);
$FARM_j$	=	structural farm differences (j = 1,..71);
FYA_k	=	first year adjustment (two levels: k = 1 in the first year that an MIS is mentioned; otherwise k = 0);
MIS_l	=	MIS effect (l=0: no MIS use; l=1: MIS use);
$FARM \times MIS_{jl}$	=	interaction between farm effect and MIS effect; and
e_{ijkl}	=	mutually independent error terms: $N(0,\sigma^2)$.

The significant main effects, ie, YEAR, FARM, FYA and MIS and the interaction FARM x MIS accounted for 80% of the total variation of the number of piglets per sow per year (R^2=0.80). With this model, the effect of MIS on the number of piglets per sow per year was estimated. The average value of the FARM x MIS-interaction-term was added to the 'pure' MIS effect. This resulted in an average MIS effect of **0.56 piglets** per sow per year. This means that using MIS increased the level of the yearly production by 0.56 piglets per sow (from the second year of MIS use onwards). The profit of MIS use equalled US$15 to US$17 per sow per year, meaning a return on investment of 220 to 348% and 7.7 to 8.7% of a farmer's typical income per sow per year in the Netherlands.
Another important outcome of the study was that the MIS profitability differed significantly

among farms. An in-depth analysis on the differences among farms was conducted, using the sociological classification methods that were included in the survey study in 1992. Farmers were divided into categories based on their management quality and styles of farming. 'Styles of farming' is a self-classification method. In an earlier study, four short descriptions of farming styles were constructed based on 'open-attitude interviews' with pig farmers (Appendix 15.1). In the survey study, the farmers had to select the description that fitted in best with their opinion on 'how a pig farm should be managed'. The management quality classification depends on a series of questions on farmers' training and education, modernity of farm facilities, farm policy, tactical and operational planning and social aspects. The survey farmers completed the questionnaire and farm management experts rated the answers.

Analysis per category demonstrated that great differences in MIS effect exist between styles of farming. Moreover, the two most extreme categories of management scores are significantly different, suggesting a positive relationship between MIS profitability and farmers' management quality (Table 15.3).

Table 15.3 MIS effect in relation with sociological classification methods

Classification method	Category	Number of farmers per category	Number of MIS users per category	MIS effect[a]
Styles of farming	'entrepreneur'	10	7	+1.41
	'manager'	44	27	+0.42
	'pig farmer'	16	10	+0.49
	'withdrawer'	6	1	-0.69
Scores on management questions (range: 1-1000)	< 380[b]	19	9	-0.48[c]
	381-445	19	12	+0.67
	446-520	20	12	+0.38
	> 520	18	12	+1.42[c]
Total		76[d]	45[e]	+0.56

[a] Defined as changes in the average number of piglets raised per sow per year

[b] Thresholds were defined to get an equal number of farmers per category

[c] The two categories are significantly different (F-test: $P<0.05$)

[d] Five of them have not participated in the 1983 survey

[e] Fifty-four farms used MIS but only 45 of them could provide production data before and after MIS use, and thus contribute to the MIS estimate

15.4 Future outlook

Both field trials in the area of animal health and management support described in this chapter showed that it is actually possible to influence and improve farmer's management. Both studies also showed considerable differences in improvement among farms, and it is a challenge for future research to find out why and how. A disadvantage of survey studies in this respect (such as the MIS application in this chapter) is that they cannot prove causality of relationships found. Uncontrolled effects may have interfered with the relationship found. Field experiments (such as the herd health application) have greater control on intervening variables but are not frequently applied due to practical limitations. Requirements are that none of the farmers already uses the program under consideration, that every farmer participates voluntarily, and that no contamination (information exchange) between the true control and program group takes place. It is not easy to get people participate voluntarily, especially not when they are assigned to the control group. Moreover, conducting experiments in the field is time-consuming and expensive. **Experimental economics** is a means to benefit from the strengths of field experiments and to overcome some of their practical limitations (Davis & Holt, 1993). In this approach people solve decision problems in a laboratory environment that are abstract representations of the natural decision problem under consideration. The basic assumption of experimental economics is that the results, obtained in a laboratory environment, represent the more complex natural environment. Experimental economic institutions need to have some typical characteristics to achieve this (Smith, 1982). The key elements of the natural decision-making environment (eg, type of decision problems, information supply) have to be incorporated into the abstract laboratory institution. Another typical characteristic of experimental economic institutions is that the participants receive **monetary incentives**; they get paid in cash according to the effectiveness of their decisions. Experimental economics is considered a promising approach to gain further insight into the profitability of animal health and management support in general, and the differences in effects among farms in particular.

References

Davis, D.D. & Holt, C.A., 1993. Experimental economics. Princeton University Press, Princeton, New Jersey, 572 pp.

Dijkhuizen, A.A., 1992. Modelling Animal Health Economics. Inaugural speech, Wageningen Agricultural University, Wageningen, 28 pp.

Smith, V.L., 1982. Microeconomic Systems as an Experimental Science. American Economic Review 72: 923-955.

Sol, J., Renkema, J.A., Stelwagen, J., Dijkhuizen, A.A. & Brand, A., 1984. A three-year herd health and management program on thirty Dutch dairy herds. The Veterinary Quarterly 6: 141-169.

Verstegen, J.A.A.M., Huirne, R.B.M., Dijkhuizen, A.A. & King, R.P., 1995. Quantifying economic benefits of sow-herd management information systems using panel data. American Journal of Agricultural Economics 77: 387-396.

Appendix 15.1 Portraits of 'styles of farming'

Portrait 1 - entrepreneur

I consider myself an entrepreneur. My aim is to follow new developments as well as possible. I make sure that I am ready for the future. My farm is well structured. I have a good idea of what is going on on my farm because I have a strong work plan and many production figures that show me how I am doing my job. I consider it a challenge to have the best production results. I find stories of other pig farmers (in farm magazines or at peer meetings) usually not very interesting. Farm magazines and farm advisers have an important task in keeping me informed. However, I draw the conclusions myself.

Portrait 2 - manager

The economy goes on and, therefore, a pig farm has to expand to keep in pace. However, it is not my aim that the farm grows but reaches a high added value per animal. I do not envy farmers having those gigantic facilities; they have to work hard to keep their bank satisfied. I prefer having some leisure time to do something other than pig farming. To get a high added value per animal, contacts with other pig farmers (eg, peer meetings) are very useful. Farm advisers must be able to think along the many aspects of pig farming, and should not be too specialized.

Portrait 3 - pig farmer

I love working with animals on the farm. I enjoy my pigs performing well. Health care of the animals is one of my major topics in farm management and keeps the involuntary replacement costs low. I avoid risks as much as possible. Advice of the farm adviser or veterinarian are a crucial element. Technical and financial recordkeeping has to be done, but it is something I do not like and costs too much time. If the government does not put too many restrictions on pig farming, we can keep our business going for many more years because we keep a good eye on our costs and avoid risks.

Portrait 4 - withdrawer

I am a bit older and probably do not have an heir. I regularly make some new investments on my farm, but I will not expand my farm any more (even if I were allowed to do so). My investments are intended to make farming easier. I do not invest in entirely new developments such as a management information system. The farm advisers and the veterinarian give good advice which I usually implement. Governmental regulations give me an awful lot of paperwork. It is a tough job to keep pace with all of these things.

16

Disease control programs in developing countries: prospects and constraints

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Objectives

From this chapter the reader should gain knowledge of:

- the major prospects and constraints of providing disease control programs in developing countries

The examples and experience summarized in this chapter refer to various types of disease and regions.

16.1 Introduction

What is so particular about the practice of disease control in developing countries? Developing countries have received several labels over the past few years, including 'underdeveloped', 'less developed', 'third world' and 'non-industrialized'. What characterizes them? The World Bank and others have developed systems of ranking such countries on the basis of economic criteria. Three or four major criteria seem to be important in such rankings. These are (1) a 'low' gross national product per capita, (2) a 'high' proportion of peasant and subsistence farmers, with accompanying 'low' levels of education, and (3) a 'poor' infrastructural and communications network. Clearly, the qualitative nature of 'high', 'low' and 'poor' means that there is a wide variation in the stage of development within the developing world; too simplistically, distinctions are routinely made on a purely geographical basis, between East Asia, Latin America and Africa. However, this wide variation in the degree of development applies also within each of these three geographical areas. Thus, although this chapter will be restricted for the most part to considering Africa, they will also have relevance to other parts of the developing world.

How do the characteristics of developing countries relate to differences in animal disease control? This is best considered by examining the principles of disease control, and exploring how the attributes of developing countries affect them. Effective disease control has four major requirements:

- problem identification and characterization;
- availability of effective disease control technologies (vaccines, drugs, etc.);
- methods to deliver the technologies and the knowledge as to their effective use; and
- successful adoption and use of control measures by farmers.

Clearly, all of these features are constrained in developing countries to a greater or lesser degree. Historically, the first three of them have generally been centralized under government control, while the fourth has been largely ignored; people have been expected to do what they are told. However, the dramatic reductions in funding to government veterinary services in many regions of the world, accompanied by calls for new thought on the delivery of veterinary services (Anteneh, 1983, 1985; De Haan & Nissen, 1985; De Haan & Bekure, 1991; Schillhorn van Veen & De Haan, 1994) are leading us to reconsider how effective disease control can still be achieved under the constraints experienced in many developing countries. In this chapter prospects and constraints are considered for improved disease control programs under the four features of disease control provided above.

16.2 Problem identification

Historically, determining the disease constraints in many countries of the developing world has been an exclusive responsibility of government, mostly run through passive disease reporting systems, and in the past this has often been restricted to a limited section of the livestock production systems in a country. From the turn of this century, when much of Africa was colonized by European settlers, until the political independence of most African countries achieved in the early 1960s, disease control priorities were determined largely on the basis of the problems affecting the livestock enterprises of the settler communities, and effected by government veterinary services serving these communities. Veterinary officers made regular reports of conditions diagnosed clinically during the course of their duties, and the few veterinary diagnostic laboratories reported their findings on the samples submitted to them. This focus of problem identification on the commercially orientated producers made economic sense at the time, given the much higher economic output of the European-run livestock enterprises. As far as disease reporting was concerned, data were reasonably representative of their production systems in this passive disease reporting, given the economic resources, relative mobility and level of education of the veterinary officers responsible. At independence, this system of disease reporting remained in place, and has continued in most African countries to this day. But the conditions under which it operates have changed dramatically in some countries, rendering it ineffective in many places. First, the livestock populations it serves have changed in three major ways - the subsistence and peasant farmers have demanded the same services previously largely restricted to the large-scale farmers; the proportion of large-scale farmers has reduced dramatically; and the production systems themselves have changed in many areas as a result of increased human population density and higher levels of demand for livestock products, among many other factors. Second, the 'diagnostic capacity' of the government veterinary services has declined. This is due to both a decline in government funding to such services, reducing the frequency and quality of daignoses made, and the extension of the service to a much larger farming community with far less in the way of economic resources to expend on veterinary diagnostic services. Third, both of these factors have resulted in disease reporting becoming unrepresentative of the farms and production systems of many countries, affecting the appropiateness of resource allocation to disease control programs. The constraints are clear, but what are the prospects?

The identification and characterization of animal health problems cannot be effectively achieved through the passive disease reporting systems still in place in much of Africa, a conclusion endorsed at a recent Expert Committee of the Food and Agriculture Organization of the United Nations (FAO, 1995). This group advocated more focused, **active studies** on subsets of the population to tackle specific diseases of concern, or specific production systems and geographical areas of interest. These might be achieved through carefully designed sample studies (eg, Deem *et al.*, 1993) or through prospective studies (eg, Gitau *et al.*, 1994), in which disease incidence and the relationship between disease and productivity loss can be measured. Not only should much of the emphasis in design be moved from passive reporting to active studies, but there should also be a clear division of responsibility for financing this work. Thus governments, intent on safeguarding their international trade in livestock and livestock products, for example, should be responsible for reporting on diseases which severely disrupt this, such as foot-and-mouth disease and rinderpest, whereas farmers should be responsible for sponsoring the reporting of diseases affecting their levels of production, such as mastitis and reproductive disorders, in order that they can use this information to enhance their outputs. However, some diseases do not fall clearly into either of these categories, and these include those affecting human health. Furthermore, governments, possibly assisted by universities, are likely to retain responsibility for geographical areas and production systems with very low economic outputs, for reasons of equity and social welfare. But it is not as simple as that, and herein lies one of the greatest prospects for improved productivity in the developing world. The developed world has shown that the involvement of farmers themselves in problem identification through production performance recording schemes has yielded huge returns in terms of increased production efficiency. Whereas it is not to be foreseen that every smallholder dairy farmer in Africa will have a notebook computer for a few years yet, there is an opportunity for dairy cooperatives, farmers societies and product societies to make effective use of the surplus veterinary manpower in some countries to develop performance profiles for the production systems of their members, the first step towards **farmer-driven** problem identification and decision support systems (Van Schaik *et al.*, 1995).

16.3 Effective disease control technologies

The poor availability of drugs, vaccines and chemicals has often been cited as the main reason for suboptimal animal disease control in Africa. Although there are several diseases which severely constrain livestock productivity and development for which no adequate control measures are at our disposal (most notably trypanosomiasis and the tick-borne diseases), productivity of livestock could be enhanced dramatically if only the technologies we do possess could be effectively delivered. There are clearly several issues here. These are: technology development (through research) to produce new ways to control diseases; technology manufacture and distribution of developed products; and technology delivery to the farmers to reduce the effect of poor animal health on livestock productivity. It is the first two of these that will be considered in this section (the third will be addressed in the next one).

The world still does not have effective means to prevent some of the infectious diseases that are widely prevalent in the developing world. These diseases include trypanosomiasis, theileriosis, cowdriosis, babesiosis, anaplasmosis and dermatophilosis among many others. For all of these, drugs to treat infections exist and are widely available, but given their high cost and the constraints to their timely delivery in the early stages of infection in order to be effective, they are not a sustainable option for many production systems in the developing world. Disease prevention is thus a more sustainable approach, and this generally means vaccines (as well as the exploitation of genetic resistance to diseases). For some of the infections mentioned, vaccines are available, but the lability of many of them (such as the blood-based and tick stabilate 'vaccines' which require strict refrigeration) renders them difficult to deliver in many production systems of the developing world, and inappropriate in others. Thus much basic strategic research remains to be done to develop effective and safe vaccines for these infections which are appropriate for use in the developing world. Within the Consultative Group on International Agricultural Research (CGIAR) this has been the role of the International Laboratory for Research on Animal Diseases (ILRAD), in conjunction with other animal health institutes and universities in the developed and developing world.

It must be pointed out that some very safe and effective vaccines already developed have not had the impact that they were intended to have, and although the cause of the failure generally lies with the distribution and delivery mechanisms, this can be addressed in some cases by research into enhancing the qualities of the vaccines themselves. One example is the rinderpest tissue culture vaccine, shown to be highly effective, but requiring a fairly strict cold chain to maintain its efficacy. Efforts to render the vaccine less thermolabile while maintaining efficacy have had a considerable influence on improving the delivery of potent vaccine to inaccessible and climatically inhospitable regions, thus enhancing rinderpest prevention and control in Africa (Mariner *et al.*, 1990). Another example is rabies tissue culture vaccines, which have effectively controlled canine rabies in those countries of the developed world in which the disease is endemic. Attempts are now being made to develop oral rabies vaccines for dogs similar to those developed for European fox populations (Perry *et al.*, 1988), to enhance the effective immunization of dogs in Africa and elsewhere in the developing world where vaccination programs using traditional injectable vaccines have not achieved the levels of coverage and population immunity required to control the disease (Perry & Wandeler, 1993).

In the cases where disease control technologies do exist, their manufacture and distribution in Africa is far from optimal, and influenced by many economic and political factors. Since the early decades of this century, many products, in terms of drugs and chemicals, have been imported from the developed world, and this has presented problems of irregular availability and low affordability. As local currencies have progressively declined in value, and foreign exchange has become a scarce commodity, disease control programs based on imported products, such as tick-borne disease control through the use of acaricides, have become increasingly unsustainable economically. As far as vaccines are concerned, there has been a serious attempt to produce them locally, and the bacterial vaccines against blackleg, anthrax and haemorrhagic septicaemia, for example, are produced in many African countries. Following independence, this process of local production was intensified, and Africa is now almost overendowed with vaccine production units. However, many of these have suffered from technical difficulties resulting in variable or low quality products. For example, many countries set up production of rabies vaccines, but several have experienced difficulties in sustaining their output and quality control, while at the same time more efficacious and much cheaper vaccines were becoming available worldwide from a limited number of commercial producers in the developed world. On face value, these latter products made economic sense, but the decision as to whether to buy international or produce vaccine locally was often complicated by other issues, such as the political desire to enhance national capacity and create employment opportunities. This situation has changed over the past few years with structural adjustment programs, and local currencies are now freely convertible on the foreign exchange markets in many African countries. If this trend continues, it will promote the prospect for more regional and international cooperation in vaccine manufacture and marketing, and enhance the prospect for more economic efficiency in the pharmaceutical industries of the developing world.

16.4 Methods to deliver technologies and knowledge

African veterinary services, dominated by the control of infectious diseases since their inception at the beginning of this century, have traditionally been centralized and largely run by governments. In the first half of the century, they were predominantly concerned with the infectious diseases affecting the commercial farming sector, as well as providing 'fire-engine' services to the peasant sector. Following independence, while maintaining a centralized government-run service, the system experienced a strong change of emphasis in the target clients, from the commercial to the peasant and 'emerging commercial' farmers, and with services delivered to these groups free of charge. In some countries, such as Zambia and Mozambique, a network of state ranches and dairy farms developed, also the beneficiary of government veterinary services. In general, there has been a gradual decline over subsequent years in the ability of governments to effectively deliver veterinary services, and the past decade or so has seen many attempts to introduce varying degrees of **cost recovery** as a way to maintain the government service. These have generally not been effective. A notable exception to the decline in control of infectious diseases has been the successful control of rinderpest throughout much of Africa, but this has been the result of substantial donor support over several years. Africa has had few successes in the area of disease eradication. The first on a large scale was the eradication of East Coast fever from much of the southern part of the continent, achieved between 1917 (when southern Mozambique was declared free) and 1960 (when Swaziland became the last country of the region to eradicate the disease (Lawrence, 1992; Perry & Young, 1993). The success is put down to highly effective veterinary services supported by legislation which was strictly enforced.

In the mid-1960s, a campaign was mounted to attempt the eradication of rinderpest from Africa, named Joint Project 15 (JP15). It started in West Africa, and extended eastwards, vaccinating cattle annually for three years through a massive operation run on military lines, conducted with the assistance of large teams of expatriate veterinarians and funded by several donor agencies. The follow-up vaccination of calves was left to government veterinary services to carry out, but many countries could not cope. Thus despite such an heroic effort, the disease re-emerged in the late 1970s and once again spread across the continent. A new campaign was devised and initiated in 1986, the **Pan African Rinderpest Campaign** (PARC), but this time the methodology was less spectacular, and it included a strong component of strengthening national veterinary services, so that should the campaign not be 100% in any area, the local veterinary service would have the capacity to limit the spread of any outbreak. Despite the apparent success of this second attempt, massive amounts of external aid have again been required to achieve this. And we are not quite out of the woods yet, with the disease persisting in areas of Ethiopia and Sudan where large cattle populations exist in regions affected by civil strife.

What is the future of veterinary services in Africa? Several authors have debated the issue (Anteneh, 1983, 1985; De Haan & Nissen, 1985; Leonard, 1987; De Haan & Bekure, 1991; Schillhorn van Veen & De Haan, 1994), but changes are slow to occur. There is general acceptance of the need to make veterinary services financially self-sustaining, and as part of this, to share responsibility for disease control between the public and private sectors, with the relative contributions of each sector dependent upon the significance of the disease in question, and the type of control measures required. De Haan & Nissen (1985) differentiate veterinary activities as to whether they are in the public or the private good, whereas Leonard (1987) sees the public sector running preventive measures, and the private sector running curative measures. The situation is believed to be much more complicated. In broad terms, the future requirements of government veterinary services will be progressively focused on diseases: (1) that affect international trade in livestock and livestock products (such as foot-and-mouth disease, rinderpest, contagious bovine pleuropneumonia, (2) that affect public health (such as brucellosis, rabies, Rift Valley fever), (3) that require coordinated large-scale operations in order to be effective (such as tsetse-fly control), and (4) that affect resource-poor communities or geographical areas.

So who takes responsibility for tick-borne disease control, given that these infections do not clearly fall into the first three categories? Until such time as the private sector can cope with the technicalities of tick-borne disease control, and farmers are willing to pay for the services provided, it is envisaged that there will be a need for broad-scale (such as national) planning of tick-borne disease control that will require standard methodologies to determine their relative importance, both for appropriate resource allocation and for control strategy development. Thus some public sector involvement for the foreseeable future seems unavoidable.

The need for the private sector, in other words the farmers, to pay for services to investigate, treat and control those diseases which limit the productivity of their livestock, is clear and recognized. This differs from Leonard's (1987) concept that only curative (but not preventive) measures are in the private good, but is consistent with the suggestions of De Haan and colleagues. The problem lies in making this work in the developing smallholder farming sector, where farmers are economically constrained. In some areas such farmers keep only one or two improved cattle, lacking as individuals the critical mass to attract private veterinary services. In the areas of eastern Africa where smallholder dairying is an important component of the mixed farming systems, it is easy to envisage that the farmers societies and dairy cooperatives could play a central role in providing the resources to employ veterinary staff, and to deliver effectively a wide range of services. However, this is not so easy to envisage elsewhere, such as in areas of central Zambia or the communal lands of Zimbabwe for example, where milk plays a much smaller role, cattle have more traditional value, and their strongest economic role is in traction for ploughing. Regrettably there is little tradition for private employment of qualified veterinarians to serve these farming communities, so in many areas the continued use of the government veterinary department infrastructures, but with a full cost recovery for such services provided, will probably be a compromise transition for many years.

16.5 Successful adoption and use of control measures by farmers

Mounting centrally-planned disease control programs is one thing, but having farmers and livestock owners comply with instructions and procedures can be another. Nevertheless, successful adoption and use of control measures by farmers is critical to both public and private sector instigated programs if livestock production efficiency is to be enhanced.

For public sector initiatives, this need for a greater understanding of factors affecting farmer compliance has received little attention in the past, and veterinary authorities have often been insensitive to the need for information and understanding about disease control programs on the part of the general public. The first Pan African rinderpest eradication program (JP15) experienced resistance to vaccination in some areas because the benefits to the community from freedom of the disease were not adequately explained. The more recent PARC program has a large information dissemination component to address this. There are similar examples with other diseases. Perry *et al.* (1995) demonstrated that dog rabies vaccination coverage in high population density city suburbs could be enhanced considerably if more time was spent in each area covered by vaccination teams, if **children** (the guardians and companions of much of the dog population) were involved in the vaccination campaign during their school holidays, and if house to house visits were made in addition to the traditional vaccination points.

Education of the public is particularly important where changes in control strategy or policy are implemented. In Zimbabwe, the Veterinary Department has abandoned its policy of intensive tick control of cattle in the Communal Lands to control tick-borne diseases, and is moving towards a situation of widespread natural immunity to many tick-borne infections through endemic stability. However, it is proving very difficulty to change the attitudes of people, both the stock owners and the staff of the Veterinary Department, who have for almost four generations been warned of the evils associated with ticks, and who now are being told of the benefits of living in harmony with them.

Some work has been done to try and better understand local indigenous knowledge of diseases in order to structure appropriately the message to the public accompanying disease control programs. Such ethnoveterinary studies have been carried out in Kenya on cattle diseases (Delehanty, 1991). It is likely that this subject work will become more important as public support to and adoption of programs play a greater role, and legislation becomes increasingly difficult to enforce.

With the decline in government veterinary services, attention has been paid to the role of **community-based** disease control programs for some of Africa's infectious diseases, and the most notable example has been control of tsetse flies and the trypanosome infections they transmit. Some argue that tsetse fly control requires central planning and implementation to be effective, and Zimbabwe provides an excellent example of how such an approach can work. However, not every country has the veterinary infrastructure of Zimbabwe, and community-based programs using odour-baited targets and traps have been studied in many countries. Probably the most successful example has been at Nguruman in Kenya (Dransfield *et al.*, 1991), where a community-managed control program based on local production, maintenance and deployment of insecticide-impregnated targets was established, financed by the commercialization of wildlife and handicrafts by the Maasai occupiers of group ranches. However, the sustainability of such operations without donor support and funded technical advice is still questioned. Nevertheless, the prospect of greater involvement of communities in disease control programs presents yet a further opportunity for improved disease control in developing countries.

References

Anteneh, A., 1983. Financing animal health services in some African countries. International Livestock Centre for Africa. LPU Working Paper No.1. Addis Ababa.

Anteneh, A., 1985. Financing livestock service in some countries of East and southern Africa. International Livestock Centre for Africa. LPU Working Paper No.6. Addis Ababa.

Deem, S.L., Perry, B.D., Katende, J.M., McDermott, J.J., Mahan, S.M., Maloo, S.H., Morzaria, S.P., Musoke, A.J. & Rowlands, G.J., 1993. Variations in prevalence rates of tick-borne diseases in Zebu cattle by agroecological zone: implications for East Coast fever immunization. Preventive Veterinary Medicine 16: 171-187.

De Haan, C. & Bekure, S., 1991. Animal health services in sub-Saharan Africa. Initial experiences with new approaches. The World Bank, Washington, D.C.

De Haan, C. & Nissen, N.J., 1985. Animal health services in sub-Saharan Africa. The World Bank. Technical paper No.44F. Washington, D.C.

Delehanty, J., 1991. Local knowledge of cattle diseases: methods and results from a study in coastal Kenya. In: Ethnoveterinary Research and Development (C.M. McCorkle & E. Mathias-Mundy, eds), Kegan Paul International, London.

Dransfield, R., Williams, B.G. & Brightwell, R., 1991. Control of tsetse flies and trypanosomiasis: myth or reality. Parasitology Today 7: 287-291.

FAO, 1995. Report of an expert consultation on the need for information systems to strengthen veterinary services in developing countries, Rome.

Gitau, G.K., McDermott, J.J., Waltner-Toews, D., Lissemore, K.D., Osumo, J.M. & Muriuki, D., 1994. Factors influencing calf morbidity and mortality in smallholder dairy farms in Kiambu District of Kenya. Preventive Veterinary Medicine 21: 167-177.

Lawrence, J.A., 1992. History of bovine theileriosis in southern Africa. In: The Epidemiology of Theileriosis in Africa, R.A.I. Norval, B.D. Perry & A.S. Young, Academic Press, London: 1-39.

Leonard, D.K., 1987. The supply of veterinary services: Kenyan lessons. Agricultural Administration and Extension 26: 219-236.

Mariner, J.C., House, J.A., Sollod, A.E., Stem, E., Van den Ende, M.C. & Mebus, C.A., 1990. Comparison of the effect of various chemical stabilizers and lyophilization cycles on the thermostability of a Vero cell-adapted rinderpest vaccine. Journal of Veterinary Microbiology 21: 95-209.

Perry, B.D. & Wandeler, A.I., 1993. The delivery of oral rabies vaccines to dogs: an African perspective. Onderstepoort Journal of Veterinary Research 60: 451-457.

Perry, B.D. & Young, A.S., 1993. The naming game: The changing fortunes of East Coast fever and Theileria parva. Veterinary Record 133: 613-616.

Perry, B.D., Brooks, R., Foggin, C.M., Bleakley, J., Johnston, D.H. & Hill, F.W.G., 1988. A baiting system suitable for the delivery of oral rabies vaccine to dog populations in Zimbabwe. Veterinary Record 123: 76-79.

Perry, B.D., Kyendo, T.M., Mbugua, S.W., Price, J.E. & Varma, S., 1995. Increasing rabies vaccination coverage in urban dog populations of high human population density suburbs: a case study in Nairobi, Kenya. Preventive Veterinary Medicine 22: 137-142.

Schillhorn van Veen, T.W. & De Haan, C., 1994. New trends in the organisation and financing of livestock and animal health services. The Kenya Veterinarian 18: 24-25.

Van Schaik, G., Perry, B.D., Mukhebi, W.A., Gitau, G.K., Dijkhuizen, A.A., 1995. An economic analysis of smallholder dairy farms in Murang'a District, Kenya. Proceedings of the 8th International Conference of Institutions of Tropical Veterinary Medicine, Berlin, 76.

17

How do we integrate economics into the policy development and implementation process?

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Objectives

From this chapter the reader should gain knowledge of:

- animal health being only one constraint affecting livestock production systems
- factors that influence cost recovery for animal health services
- the importance of an integrated approach in livestock development programs

17.1 Introduction

This chapter is intended to describe applications for the various economic techniques in the process of planning and implementing animal health programs. The most important point is that animal health economics cannot be considered in isolation when it comes to formulating and implementing development policy. Animal health is only one of the constraints affecting livestock systems, and it is not usually sufficient to address only animal health constraints: other problems may prevent potential benefits of improved health from being realized.

It must also be emphasized that the situation is dynamic: removing an animal health constraint may result in fundamental changes to production systems (eg, the adoption of different livestock breeds). The new production systems will face a new range of constraints, including new disease problems.

These points may seem obvious, but far too many animal health (and other livestock development) programs have failed because they were based on inadequate policy analysis, especially in the developing world. A notable exception is the 'Operation Flood' milk cooperative movement in India, and it is significant that these programs have provided interventions in milk marketing, health, breeding, nutrition, credit and management advisory services.

Integrated livestock development programs, based on an understanding of the whole production system, have long been recognized as necessary. However, such programs are complex to plan and to manage, and the failure of one component can jeopardize the whole effort. However, the standard economic methods are compatible with the systems-level approach, and there are encouraging signs that their use is beginning to have an impact.

It must also be remembered that livestock have a long production cycle, and it takes time for the effect of improvements to manifest themselves as increased productivity and incomes.

The impact of many livestock development projects will not be apparent until some years after the end of the project (which may have been terminated because no benefits could be demonstrated).

Many developing countries have been unable to implement livestock development programs which have been shown to be economically justified, because they lack the services to implement and sustain the necessary activities. The reason for the lack of services is almost always lack of finance to operate them (lack of trained personnel is usually only a secondary problem: even if the staff were available, they could not be financed). In fact, a common problem is that although budgets may actually have increased in real terms, staff costs have steadily risen so that nearly all of the budget is used to pay (usually inadequate) salaries.

There are three approaches to dealing with this situation:

- **retrenchment**, in which staff numbers are drastically reduced;
- **privatization**, in which services are transferred to the private sector; and
- **cost recovery**, when producers pay directly for government services.

These approaches are not independent of each other, and most countries adopt a policy containing elements of all three. This has led to some confusion in the analysis of different policies. Cost recovery has important economic implications, because it directly affects the decisions and economic welfare of producers. There has been extensive debate on the suitability of cost recovery for different services, and the subject is reviewed as follows.

17.2 Cost recovery for animal health services

17.2.1 Arguments for and against

The question of cost recovery needs to be distinguished from two related issues with which it is often confused: privatization of veterinary services and the establishment of revolving funds. Private veterinary practitioners may be engaged to implement government-financed disease control programs without any cost recovery from livestock owners. This has been standard practice in many countries, and has been used to provide work and income for private veterinary practices while they become established. Further arguments in favour of the use of private veterinarians in government programs are that it may reduce costs if the private sector can operate more efficiently than government, and that it places the government service in its proper function of regulation and supervision, separating these activities from implementation with which they are incompatible. However, the use of private veterinary practitioners could reduce scope for cost recovery in government disease control programs: private veterinarians may be reluctant to compromise their relations with clients by acting as 'tax collectors'.

Revolving funds in which the revenue from cost recovery is made immediately available for continued operation of the program are often proposed as a part of cost-recovery schemes. However, they are not an essential component, and are generally opposed by finance ministries on the grounds that they are expensive to administer, increase the risk of misappropriation and make financial planning more difficult. If revenues are less than expected, a program financed by a revolving fund may collapse while, in theory at least, finance allocated from the central government budget should be available irrespective of the success of cost recovery.

The arguments for and against cost recovery fall into six main headings:

- **Sustainability** - cost recovery may be considered a more reliable source of finance for veterinary services than the central government budget in some countries;
- **Equity** - it may be argued that beneficiaries of a service should meet the cost of providing it;
- **Efficiency of resource allocation** - if a service is provided at less than its economic cost it may be applied at a level higher than the economic optimum; alternatively, it may be the case that a service given for nothing may be valued at nothing and ignored;
- **Effectiveness of disease control** - cost recovery in a disease control program would be expected to reduce the coverage, which might expose even treated animals to a high disease challenge, reducing the effectiveness and economic benefits of the whole program;
- **Economic cost of cost recovery** - in economic terms, cost recovery merely transfers the costs of a disease control program from one sector of the economy to another, and does not generate any benefit to the economy as a whole; on the contrary, it adds to the economic cost of the program; and
- **Financial efficiency** - collecting fees from livestock owners can be very difficult and expensive, especially where the treatment cannot be withheld from those unable to pay immediately. It may be the case that the financial cost of collecting the revenue is greater than the revenue itself, meaning that there is an adverse effect on government expenditure.

All of these considerations should be included when deciding whether or not cost recovery is appropriate for a particular program. The final decision will depend on weighing the advantages and disadvantages, and this will certainly involve a degree of subjective value judgment. However, better decisions can be expected if all of the issues have been taken into account. The issues to be considered are discussed in more detail in the following sections.

17.2.2 Sustainability

This is usually the principal practical argument in favour of cost recovery for veterinary services. The operational capacity of many government veterinary services has been crippled by lack of funding. The attractions of alleviating this problem by collecting revenues from livestock owners are obvious. To the veterinary services staff it could provide a more reliable source of funding to sustain disease control operations, and to the finance ministry it would offer a relatively painless way of increasing government revenue and/or reducing budget deficits. The result would be to provide sustainable long-term funding for disease control operations, without imposing additional demands on the central government budget.

Lack of operational funding may be due to any combination of three causes:

- that budgetary allocations are insufficient to maintain the services required;

- that planned budgetary allocations are not actually available for expenditure because of economic conditions or administrative problems; or
- that an excessive proportion of the funding made available to the veterinary service is absorbed by administrative and overhead costs, particularly manpower, leaving insufficient funding for field operations.

The last problem is a very common result of previous shortages of operational funding. When activities have to be curtailed, it is usually field operations that are reduced, as in the short term this is the only feasible method of reducing expenditure. To restructure the veterinary service would require reducing facilities and/or reducing staff numbers, both of which take time to implement and have political implications. It is also the case that decisions on the allocation of resources tend to be made by headquarters staff, and these are naturally reluctant to declare themselves redundant. However, cost-recovery programs are unlikely to provide a solution to this problem. If restructuring of the service is required, this difficult problem must eventually be faced. Otherwise increased funding, from any source, is likely to be absorbed in further administrative and overhead costs.

Assuming the institutional structure of the veterinary service is reasonable, then increases in funding from cost recovery have the potential to sustain field operations. However, cost recovery may not actually result in an increase in available funding. The finance ministry may simply reduce funding from the central government budget to offset any revenues from cost recovery. This might have a beneficial effect on the central government budget deficit, but clearly will not contribute to improving veterinary services.

If there is a problem of planned budgetary allocations not actually being available for expenditure due to economic conditions or administrative problems, then cost recovery by itself is unlikely to help the situation. In these circumstances any revenues collected are likely to remain in the finance ministry, subject to the same financial restrictions or administrative constraints as any other source of funding. The establishment of a revolving fund, so that revenues remain within the veterinary department and can be used to fund programs directly, can help to overcome administrative problems in the disbursement of funding. However, if the administrative barriers are in fact an instrument of government policy intended to restrict expenditure, such revolving funds are likely to be opposed by the finance ministry as they tend to undermine this policy. It is also the case that revolving funds require careful administration and audit, which will add to costs and probably duplicate systems already in existence in the finance ministry. Even if a revolving fund can be established and successfully operated, it may not guarantee the sustainability of programs. If for any reason short-term revenues are lower than anticipated, for example due to a natural disaster such as flooding or drought, then programs financed by the revolving fund may be curtailed by lack of funds at the very moment when they are most needed.

In summary, cost recovery does have the potential to provide funding on a long-term basis for some disease control operations. It is not, however, a substitute for restructuring the veterinary service where this is necessary. Where revenues are channelled through the finance ministry there is a danger that they will be regarded simply as another source of revenue from taxation. Revolving funds require considerable administrative inputs and auditing, and may not completely cushion programs from short-term financial adversity.

17.2.3 Equity

There is a strong argument for the principle that the beneficiaries of a service should meet the cost of providing it. It is, however, a mistake to assume that livestock producers as a group are necessarily the prime beneficiaries of improved livestock disease control. In the first place, control of livestock diseases may be motivated, at least in part, by the objective of protecting human health. Second, it can be shown that technological improvements in livestock production often enhance the economic welfare of consumers more than producers.

The control of zoonotic diseases is frequently undertaken with a view more to protecting **public health** than to improve livestock productivity. For example, the prime motivation for the control of brucellosis is usually to protect humans from the disease. While farmers, veterinarians and others working in the livestock industry are most exposed to zoonotic diseases, the general public and consumers of livestock products are usually also at risk, and their greater numbers may mean that they account for the majority of human cases.

Where a disease affects livestock productivity, reducing the incidence would increase the level of production. The increased production can be expected to reduce prices, and on the markets for many agricultural products the percentage price reduction can be greater than the percentage increase in production. For example, a 5% increase in production could lead to a 10% fall in prices, which would mean that producers would actually suffer a reduction of income, while **consumers** would receive more product for less total expenditure. This is by no means the case for every market, but it is quite a common situation in the markets for agricultural produce, and is the main justification for agricultural support policies. It generally occurs where the demand for a product is relatively insensitive to price, as is often the case for staple food products (see also Chapter 12).

Econometric analysis is required to identify the beneficiaries of technological improvement in any particular market. However, it is quite common in the markets for livestock products that consumers would be the main beneficiaries, especially as international markets for livestock products are limited by zoosanitary restrictions.

It should be pointed out that the livestock owner also consumes some of the production in most livestock systems, but in the extreme case of subsistence livestock production the low income of the owners may constitute an argument for government support. It is in any case difficult to collect fees from subsistence producers.

Where the main beneficiaries of disease control are consumers rather than producers, it would be equitable to impose the cost of disease control on consumers. This might be achieved through the imposition of a tax or cess on marketed livestock production, but in many developing countries the markets for livestock products are dispersed and informal. Any attempt to tax the formal markets, which already have higher costs because of meat inspection and other measures, would simply encourage more marketing through uncontrolled channels. The practical, but less focused, policy may be to raise the revenue through general taxation, which usually affects consumers of livestock products more than producers.

There is a further twist to the economic welfare argument: while it may be against the economic interest of producers as a group to adopt improved technology, the situation is different for **individual producers**. If an individual uses disease control to improve the efficiency of production, it will make no measurable difference to the price that (s)he receives. Therefore it will be in the personal interest to apply disease control, even though it is against the interest of producers as a group. The divergence of individual and group interests may mean that it is in the interests of the individual to pay fees, but this does not necessarily mean that it is equitable.

This discussion has so far omitted another aspect of equity, which is the principle that taxation should be directed at the wealthy. This chapter is concerned with the problems of cost recovery rather than the redistribution of wealth, and there are more efficient methods for redistribution of wealth than charging fees for services. The point does, however, suggest the possibility of restricting charges for services to large-scale livestock producers. This group are more likely to be able to pay fees, and larger, more intensive producers benefit more from some disease control programs than small-scale producers. The practical difficulty with the policy is to identify criteria for deciding whether a particular producer should pay fees or not.

In summary, it is a mistake to assume that livestock owners are always the main beneficiaries of disease control programs. While it may be in the interest of individual producers to control livestock diseases, producers as a group often suffer a loss of economic welfare compared with consumers of livestock products. While it may be more practical to recover the cost of services from producers, it is not necessarily equitable.

17.2.4 Efficiency of resource allocation

In the theory of production, inputs should be applied to the point where the marginal value of the additional production obtained from the use of the input is equal to the marginal cost of the input (see also Chapter 2). Assuming diminishing returns to higher levels of input usage, applying more input below this optimal level would produce additional production of greater value than the marginal cost of the input, while if the input was being used at a higher level than the optimum, the marginal value product would be less than the marginal cost.

The consequence of this theory is that if the producer were supplied with the input free of charge, there would be no economic constraint to the level of usage, and it would tend to be over-applied and thus wasted. For example, if producers were able to obtain anthelmintic free of charge, they might tend to use it at higher doses or more frequently than necessary, thus wasting resources.

A contradictory theory sometimes advanced is that if a service is available at no cost, producers may regard it as being of no value and thus disregard it. However, it is difficult to find convincing evidence in support of this: there do not seem to be any documented examples of uptake of disease control measures being improved by the introduction of fees.

Thus, producers could be expected to apply disease control at the economically optimal level, but only if four conditions were met:

- the decision on the level of disease control would have to be within their control;
- they would have to be aware of the production response to any particular level of disease control;
- they would have to receive the benefit of any production response; and
- they would have to meet the cost of the treatment.

If any of these assumptions fail, then producers cannot be relied upon to apply the optimal level of disease control. It is not sufficient to meet only the fourth condition, cost recovery, to ensure the optimal allocation of resources.

The first condition does not hold for all types of disease control. Many epizootic diseases can only effectively be controlled by mass vaccination and other measures, such as slaughter and movement control, applied on a regional or national basis. In this case the producer does not make the decision on the level of control. On the other hand, some animal health inputs such as parasite control measures can be used effectively by individual producers, who can make the decision on the level of control. There is a strong case for imposing the cost of disease control at the decision-making level, which may or may not be the individual producer. To reverse the well-known proverb: "he who calls the tune should pay the piper"!

The second condition is a matter of the experience of individual producers and extension workers to make them aware of research results. However, with regard to epizootic diseases, the individual producers face a great deal of risk and uncertainty. If their herd is affected by the disease they may face very large losses, but they may escape infection altogether. In such situations the element of risk is much less important at the regional or national level where average losses are more predictable. Therefore it is easier to assess production response to the control of epizootic diseases at the regional or national level, and thus to make rational decisions on the appropriate level of control.

The third condition, that the producer receives the benefit of any production response, is more likely to apply at the level of the individual producer than for producers as a group, as explained in the previous section. However, there are frequently external costs and benefits, ie, costs and benefits which apply to persons other than the individual producer, in animal disease control. Much of the benefit of controlling zoonotic disease may accrue to the public and consumers of livestock products, and in this case producers could not be relied upon to adopt the optimum level of control. **Externalities** are often significant in the control of infectious diseases. It can be the case that diseases cause little loss in the livestock populations which act as reservoirs of infection, but large losses when they are introduced to other susceptible populations which cannot always be protected by vaccination. To control such diseases it is necessary to apply control measures in the maintenance population, where there is much less incentive for livestock owners to meet the costs of control.

In summary, therefore, cost recovery can sometimes be expected to lead to more economic application of animal health inputs, but only if the decision is in the hands of the producers;

they are aware of the benefits and they are the recipients of the benefits. These conditions are likely to be met for the control of many parasitic conditions and other diseases of relatively low infectivity, but not for highly infectious or zoonotic diseases.

17.2.5 Effectiveness of disease control

The effective control of many infectious diseases requires high levels of participation in the disease control program. Any attempt to recover the costs of control will reduce the willingness of livestock owners to cooperate, which will have an adverse effect on the economic value of the program, either by increasing costs or reducing benefits.

This principle is very important in the control of diseases such as foot-and-mouth disease, where it is difficult to protect animals by vaccination in the face of continuing disease challenge. It is also significant in the control of diseases such as rinderpest where a single vaccination confers life-long immunity. In this case, it may be possible to eradicate the disease if high vaccination rates can be maintained for a few years; thereafter control costs will be restricted to preventing re-infection. On the other hand, it may be possible to avoid most of the loss from rinderpest by continuing lower rates of vaccination indefinitely, but the overall costs of this are likely to be much higher. Moreover, the continuing presence of infection may lead to restrictions on internal and international trade, both of which have economic costs (see also Chapter 12).

Again, this consideration is of greatest importance in the control of highly-infectious diseases, and is of less significance for conditions of lower infectivity where the actions of one producer have less impact on others.

17.2.6 Economic cost of cost recovery

Cost recovery can never reduce the cost of disease control for the economy as a whole. The charging of fees for services simply transfers the cost of the program from one sector of the economy to another. On the contrary, cost recovery adds to the overall economic cost of a disease control program. It will require time, resources and administration to collect and account for the fees, and it may be more difficult and expensive to ensure that animals are vaccinated if owners are aware that fees are to be collected. If the progress of disease control operations is delayed by the collection of fees, then the economic benefits will be reduced as the disease losses continue.

17.2.7 Financial efficiency

One of the main objectives of cost recovery is to reduce the financial cost of disease control programs to government budgets. However, the resources used in cost recovery have also to be financed, and it is quite possible that the budgetary cost of these resources could approach or exceed the revenue generated. The financial cost of cost recovery will include not only the staff and resources required to collect the fees, but also any increased costs resulting from the slower implementation of programs which is likely to result from the imposition of fees.

The cost of collecting fees will depend on the nature of the disease control program.

If participation is voluntary, then the service can be withheld from owners who are unable or unwilling to pay the fee. In this case, the costs will consist mainly of the extra administration required to handle and account for the revenue. In addition, some programs carry overhead costs, eg, travelling to villages, in addition to the direct costs of the treatment. If the charging of fees reduces participation, then the overhead costs per animal treated may be increased.

If owners cannot pay the fee at the time of treatment in compulsory programs, it will be necessary either to extend credit by agreeing to collect the fee later, or to return to treat the animals at some later date. Both of these options are inconvenient and expensive. In the last resort they will require police action and recourse to civil or criminal courts. Such measures are unpopular with livestock owners, veterinarians and police, and extremely expensive.

In some circumstances it may be possible to rely upon the local administration, eg, village headmen, to collect fees. This can substantially reduce the cost of collection, but is very difficult to control and subject to abuse.

17.2.8 Resolving the cost-recovery issue

Cost recovery for veterinary services is a very complex question, and there is no general rule as to whether it is desirable or practicable. However, having reviewed the main issues involved, it is possible to produce some general guidelines. It is clear that no government can afford to provide all possible animal health services free of charge, and that even if this were feasible it would lead to enormous wastage of resources. A policy in which each producer could decide on what level of animal disease control was appropriate to his/her circumstances and meet the costs would be equally impractical, as many diseases require organized control programs on a regional, national or international scale.

In the control of diseases of relatively low infectivity and which do not have human health implications, most of incremental production and other benefits of disease control accrue to the individual producer. Their decision on whether to control the disease or not will have little effect on other people. In this case, if the costs of control are imposed upon the producer, (s)he will be motivated to use disease control at the most economic level. Cost recovery would therefore tend to lead to rational allocation of resources. This advantage would usually be considered to outweigh the disadvantages resulting from the cost of collecting the revenue, and the fact that free and compulsory programs might have lower costs per animal treated.

Where market conditions are such that producers as a group suffer a loss of welfare by using disease control to increase production, the rather paradoxical situation develops that to subsidize voluntary disease control programs would actually work against the interest of the producer! If the program is subsidized, production will increase, resulting in a greater loss of economic welfare to producers, as well as encouraging use of the animal health input at levels beyond the economic optimum for the economy as a whole.

In the control of more infectious diseases, or those with human health implications, a proportion of the benefit of disease control will accrue to people other than the producer.

In this case, the producer's optimal level of disease control may differ from the optimum for society as a whole, and it may be necessary to impose a compulsory disease control program. To attempt to finance this by collecting fees from producers is likely to add to the costs of the program, and reduce its effectiveness and benefits. It is also possible that the costs of collecting the fees will approach or exceed the revenue collected.

In compulsory disease control programs, improved efficiency of production resulting from the control of disease may, in some circumstances, have an adverse effect on the economic welfare of producers as a group. Then the justice of imposing the cost of the program upon producers is doubtful, but the practical arguments outlined above are likely to prevail over the question of equity, which can in any case be addressed in other ways.

A practical approach to decisions on cost recovery is to require the individual or agency making the decision to meet the cost. Any departure from this principle leads almost inevitably to problems of enforcement or wastage of resources. This implies that compulsory programs for the control of epizootic and zoonotic diseases should be government-financed, while other programs and clinical services should be producer-financed. This leads to a situation in which the 'client' of economic analysis, the decision maker, also has to bear the financial and budgetary implications.

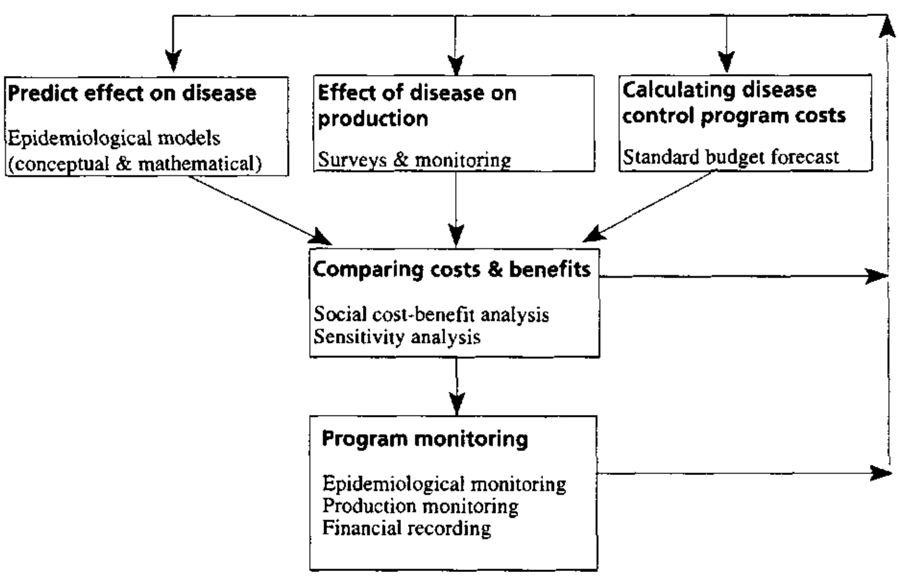

Figure 17.1 Economic analysis in government financed disease control programs

17.3 Economic analysis of government-financed disease control programs

Decisions on government-financed disease control programs are usually based on social cost-benefit analysis (Figure 17.1). The costs and benefits of the program to the economy as a whole are compared. This type of analysis is most valuable for planning purposes on an *ex ante* basis, ie, before the program is implemented. *Ex post* analysis is only of historical interest, unless it is being used to predict the effects of extending an existing program.

It is usually much easier to predict the costs of disease control programs than the benefits. To predict the benefits requires knowledge of:

- existing levels of disease and productivity;
- the effect of the program on the disease; and
- the effect of the reduced level of disease on production.

Many of the newer methods in animal health economics address these information needs. The assessment of existing levels of disease and productivity is an empirical process, depending on analysis of data produced by *ad hoc* surveys, or on-going monitoring systems. While it is sometimes possible to collect useful information on animal health and production through rapid appraisal 'snapshot' techniques, it is often found that the results of such surveys are biased. The main reasons for this are that:

- producers' recollection of livestock production and offtake tends to be unreliable. Unlike most crops, livestock do not have a single harvest period: offtake can occur throughout the year.
- most livestock species have a long production cycle, and it can take a long time for changes to the pattern of production to work through the system.
- producers have considerable flexibility in short-term management strategies. They may increase or decrease offtake rates in response to market or climatic conditions.
- many diseases follow long-term cycles (which may be related to cycles in the pattern of production).

Predictions of the effect of the program on levels of disease and of reduced levels of disease on productivity require the use of models, which range from informal conceptual models in the minds of decision makers to mathematical models implemented on computers (see also Chapters 6 to 9). The models, whether conceptual (qualitative) or mathematical (quantitative) rely on data obtained from empirical studies. In general, the availability of reliable data is the most immediate constraint to the incorporation of economics into animal health policy at the national level.

17.4 Economic analysis of producer-financed animal health programs

Where producers are responsible for making decisions on animal health programs for their own livestock, the decision will be based on economic analyses, in which the prices reflect values to the individual farm situation (usually market prices).

While many animal health services are (or should be) producer-financed, the development and extension of policies for them to implement is usually seen as a government responsibility. In general, it is not feasible to conduct individual economic analyses for individual producers. Analysis is conducted for model situations, representative of groups of producers, on the basis that the policy produced will be appropriate for all producers in that group (Figure 17.2). This means that *ex post* analysis can play a more important part in the analysis of producer-financed animal health programs. Before a policy is

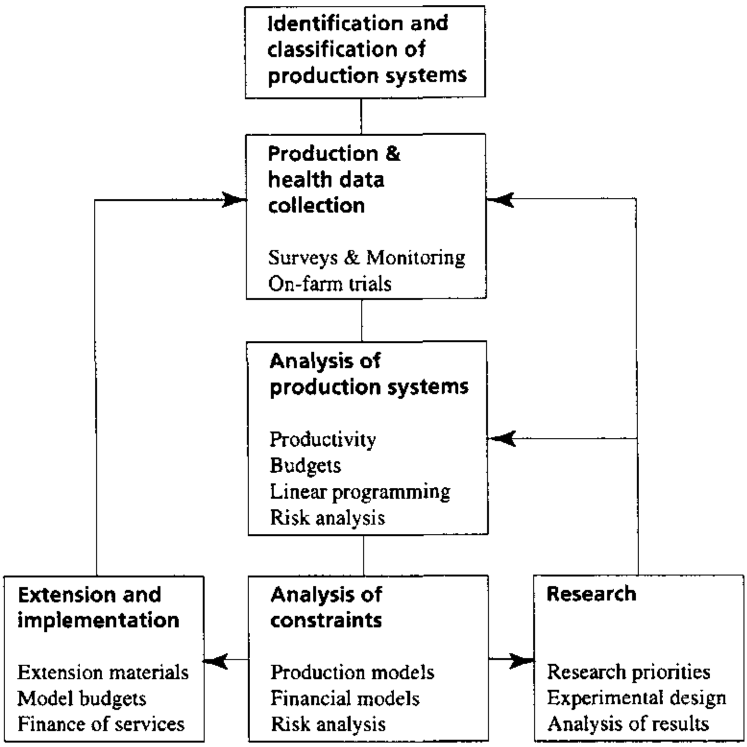

Figure 17.2 Economic analysis in producer-financed health programs

recommended for general application it can be tested in field trials. The results of these analyses based on empirical studies are more reliable than those based on predictive models (which might have been used to design the policies for pre-extension trials).

The use of computer-based herd recording and management systems does allow automated economic analysis of policies for the individual herd. At present, these automated analyses are based upon the results of studies in other herds, but there is a trend towards using the records of the individual herd as a basis for the prediction of future performance of that herd.

In many developing countries, livestock producers have very limited access to animal health and production services, and the private sector offers the only prospect of providing services in the future. Economic analysis of livestock services in these situations needs to consider not only the effect of services for the producer, but also the financial profitability and viability of providing the services.

17.5 Economic analysis of research priorities

With increasing pressure on government budgets, there is increasing demand for economic analysis of livestock research programs. In particular, sponsors are demanding that research be prioritized and resources be directed to programs that will produce the greatest economic return.

The economic analysis of research is complicated by the fact that the benefits depend on results, which are by the very nature of research uncertain. It is also necessary to take into account the likelihood that new technologies will be adopted by producers: there is no value in producing a new technology if producers lack the services to use it, or if they find it socially unacceptable. These problems of probability of success and uptake of results can only be judged subjectively, which means that different individuals will produce entirely different rankings of research priorities.

The approach which has been most widely applied in the economic prioritization of research programs has been to identify constraints to production systems, and then to estimate the economic benefit that would result from the removal of the constraint. Weightings are applied to this figure to adjust for probabilities of success and uptake, resulting in a ranking of research topics. These then have to be reviewed in comparison to the probable cost of producing a technological solution to the constraint.

Even then, the ranking is only tentative, because other factors will also be significant. The research topics are not independent: the success of one technology may depend on the development of another. There is a need to maintain capacity to undertake research in a broad range of disciplines to meet future needs: if a department is closed down this year, it could take years to re-establish the facility in future.

17.6 Institutional arrangements for livestock policy analysis

Animal health policy is only one component of livestock development policy. Much of the information needed for the economic analysis of animal health is the same as that required for the analysis of other aspects of livestock production, and the economic effect of animal health constraints is totally dependent on the **whole production system**. It would be both wasteful and ineffective to maintain separate groups of staff responsible for animal health economics and other fields of livestock economics.

Historically, veterinary services have accounted for a high proportion of livestock development expenditure in many countries. This has led to more urgent consideration being given to the economics of animal health than of other aspects of production. The techniques developed in the discipline of animal health economics have proved applicable to the analysis of other constraints. Indeed, as discussed above, techniques developed for the economic analysis of animal health in isolation would be useless. Therefore, the most important challenge for animal health economists is to produce policy not only for animal health services, but for livestock development in general. In institutional terms, this requires the development of livestock policy units serving all branches of government livestock services, as well as the private sector.

18

Building a spreadsheet model

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Objectives

By the end of this chapter the reader should be able:

- to understand the basic principles of spreadsheets
- to design simple spreadsheet models
- to include risk features into spreadsheet models

18.1 Introduction

When economic analysis first gained acceptance as a decision-making aid in veterinary science, every analysis had to be conducted completely by hand - frequently involving hours of calculations and double-checking. Since then electronic spreadsheets have made the task relatively simple even the first time, and even easier to do if the same analysis must be re-run with new data.

Because repeated financial calculations are very commonly used in business, the spreadsheet caught on like wildfire over a decade ago, and became a major factor in the growth of personal computers. Spreadsheets can be just as useful in veterinary work as in other fields, and this chapter explains the application of the technique at various levels of sophistication. They offer a way for the novice to first develop a simple partial budget, but they offer the expert a powerful shortcut to conducting complex modelling and analyses.

18.2 Structure of spreadsheets

18.2.1 Cells

An electronic spreadsheet consists of a table of individual 'cells', m columns wide by n rows deep. Columns are usually designated by letters and rows by numbers. A cell is therefore uniquely designated by its column letter and row number, such as cell B12, which is the cell at the intersection of the second column and 12th row. The width of columns may be varied to suit the particular needs.

Cells can be allocated to particular uses. Common uses include text fields for labels of various kinds, data fields which expect the user to enter values when the spreadsheet is run, and calculation fields, which contain the results of calculations based on the data which are entered. The unique feature of spreadsheets which makes them so valuable is the ability to attach a calculation formula to a cell, so that every time a new value is entered in a data entry field which affects a calculated field, the calculation is carried out again either on request or (usually) automatically, so that new values appear in all relevant cells as soon as a number anywhere in the spreadsheet is changed.

The formula for a cell can be viewed and edited at will, making it easy to check its accuracy. Once the formula is checked and permanently stored as part of a particular named spreadsheet, it can be relied on to repeat the calculation accurately as often as wished.

This feature differs from a database management program, which allows manipulation of data entered, but usually requires a formula to be applied to a group of cells by specific decision of the user, and does not allow automatic formulae to be attached to single cells with cross-references to other cells.

18.2.2 Advanced calculation procedures

The formulae in cells can include all of the standard arithmetic operations, but in addition a variety of more advanced operations which allow the spreadsheet to act as a full economic analysis system. For example, the discounting procedure for cost-benefit analysis is available as a standard operation which can be called by its name and applied to a series of annual cost or benefit figures to make cost-benefit analysis easy.

Sequences of calculations which must be carried out repeatedly for a particular application can be automated by means of a recorded set of steps called a **macro**. This can be run to conduct more complex analyses than can be achieved by simply editing data fields in the spreadsheet. Modern macro languages allow almost full programmability of the spreadsheet, permitting it to do things not envisaged by the original designer of the program.

18.2.3 Linking to other functions

Almost all spreadsheets now have databases linked to them, and powerful graphics components, which allow them to take data in a spreadsheet and turn it immediately into a graph of the user's choosing, with many additional features available to create impressive graphical displays of results of spreadsheet analyses. Because the graphing is integral to the spreadsheet, graphs can be easily updated when new data are entered. Some also have presentation creation modules, which allow computer-operated slide shows to be created directly from the spreadsheet information and directly entered text, to give public presentations of findings.

Because spreadsheets are a major component of total software sales, many smaller companies have developed creative **add-on modules** for other companies' spreadsheets, to carry out functions not available within the main spreadsheet. Some of these enhance spreadsheet function, such as the program @RISK, which extends the analytical capacity of the spreadsheet in ways to be described below (see section 18.5). Others add totally new functions, even as extreme as making the spreadsheet double as a word processing program, something for which it was never designed. So if you have a special need and the feature is not offered by your spreadsheet, you may be able to buy it and 'attach' it to the spreadsheet.

Spreadsheets which operate under Microsoft Windows have far greater capacity than MS-DOS programs to pass information automatically between different programs. This uses two techniques - Object Linking and Embedding (OLE) and Dynamic Data Exchange (DDE). They are best explained by examples. Object embedding means that an 'object' (table of analysis results, graph, etc.) is taken from one program (here the electronic spreadsheet, which is known as the OLE server because it provides the data) and embedded as an exact copy in a file of another program (commonly a word processing program, which is acting as an OLE client or user). This could also be done by pasting through the Windows clipboard, but in that case all connection with the original program is lost. When an object is embedded, and you then click on the object with your mouse in the client application, the computer will automatically load the program in which the object was created and the file which contained the original object. You can then edit it and close the 'server' application, which will return you to the client application and the file you were working on, but with the modified object now appearing on the screen.

When an object is linked rather than embedded, there is a direct linkage between the file in the client application and the file containing the 'object' in the server application. If you change the source file in the spreadsheet, next time you load the client file in your client application it will change the information in the object item to match the data in the source, without the user needing to manually make the changes or even know what the changes are.

When DDE is used, the linking of files is two-way. If a change is made in the file in either of the pair of dynamically connected programs, the 'twin' file in the other program is automatically updated before using it next time.

How does this make spreadsheets more powerful? When working on a report which includes a number of graphs and tables copied from the spreadsheet economic analyses, you can then embed each of them within the document. For modifying the layout or other features, you can go back into the spreadsheet to do it, and keep agreement between the files in the two programs, using all the power of the spreadsheet from within the word processing program. Moreover, you can embed an object in a report and complete it, then later change the spreadsheet file but the graph in the report will stay as it was when you finished the report. This is how embedding differs from linking. Linking can be very useful if you periodically have to update a document (a monthly report to a farmer or to senior managers). It always contains the same tables but the data must reflect new information, such as income and expenditure for the most recent month. Each time the document is opened, it checks to see if the spreadsheet has been altered, and if so it will update the linked objects in the word processing document to make them agree with the spreadsheet. By creating a spreadsheet to store the data and linking them to the report, you can automate and simplify the procedure of producing the monthly report. Dynamic data exchange is the most complex of these procedures to operate, but can be very useful in selected cases - for example if data are coming in continuously into a database through daily entry of new records, and you want to maintain a spreadsheet file containing summaries of the data accurate up to the latest records entered.

18.3 Choice of program

Fashions change in spreadsheets, and the program Visicalc which started the whole trend has disappeared from the scene. For much of the 1980s the dominant program in the market was Lotus 1-2-3, because it added new features and simplified the way of working with the spreadsheet, but it has lost its dominance. Of the large number of spreadsheet programs developed since Visicalc, three Window programs now dominate the market: Excel (Microsoft), Lotus 1-2-3 (Lotus/IBM) and QuatroPro (Novell). Most active spreadsheet users work in Windows because of the ability to handle larger spreadsheets, to display superior graphics, print to any printer and to use OLE. The spreadsheet templates supplied with this book will run in all of these. Each program has its own file format, but each can read some of the competing formats as well.

18.4 Formulating a simple economic analysis

18.4.1 Partial budgeting as an example

The most common form of economic analysis used at farm level will be a partial budget. Using as an example a budgeted analysis of parasite control in sheep which was originally prepared by hand (Anderson *et al.*, 1976), the net benefit of the control program using one treatment strategy can be laid out as shown in Figure 18.1. The analysis for this paper had taken a full week of work, but could now be done in a spreadsheet in a fraction of the time, and with greater accuracy.

In the form of a partial budget the analysis fits easily into a spreadsheet format. Column A will be used for row descriptions, and the first row or two in each of the other columns will be used for column headings. In this simple form column B will be used for the data and calculations. Cells can be designated to receive the raw data for the analysis, with blank cells to separate each group of related items from the others. It is important to make the layout easy to read and interpret. There are plenty of rows and columns to use, as long as you keep everything you need to work on at one time on a single screen.

An important basic rule is to have each data item entered in exactly the form it was collected, and have the program do any pre-processing to get the figures into the right form for analysis. For example, put in wool weight and price per kg, and have the program calculate fleece value. Similarly, if you must adjust the figures to take account of deaths during the year, design the spreadsheet to accept figures for the number of deaths, and use this to adjust other parts of the analysis. This saves considerable time, frustration and mistakes - especially when you are trying to do an analysis in front of a farmer.

Cells are designated to receive calculated values derived from the various raw data items, and formulae are entered into these cells to produce the result automatically. Variables used in a calculation are identified by the cell in which they can be found, while constants are entered as numbers. Mathematical operations are designated in the usual way seen on the right-hand side of a mathematical equation, using the representation of each operator required by the particular spreadsheet.

Figure 18.1 Simple spreadsheet: Benefit of 'critical' parasite control strategy over 'no treatment'

1	**Column A**	**Column B**	**Calculation formula**
2	**1. Additional returns**		
3			
4	Additional fleece wool	40	
5			
6	Capital value of surviving sheep		
7	in critical treatment group	263	
8			
9	Increased value of crutchings	2	
10			
11	Total	305	B4 + B7 + B9
12			
13	**2. Returns foregone**		
14			
15	Capital value of surviving		
16	sheep in no treatment group	222	
17			
18	Wool salvaged from dead sheep	0	
19			
20	Total	222	B16 + B18
21			
22	**3. Extra costs**		
23			
24	Extra anthelmintic and labour	13	
25			
26	**4. Reduced costs**		
27			
28	None relevant	0	
29			
30	Net return	70	(B11+B28)-(B20+B24)
31			
32	Return on invested funds	538	B30 x 100/B24

Do not try to encompass the entire calculation in a single formula, but use extra cells somewhere in the worksheet to show critical intermediate steps in the calculation. By scanning these, errors and unexpected findings can be identified.

Clearly identify the final result and make it easy to view the result cells once the data items have all been entered.

Once the basics of spreadsheet design have been learned, such a spreadsheet can be designed and implemented almost as fast as doing the calculations once by hand, and can then be re-used and varied as much as required. It is also easy to prepare **generic** spreadsheet 'templates' for commonly used analyses, which carry out calculations on blocks of cells, so that a single worksheet can be used for a variety of purposes by simply converting the generic block of rows for 'extra costs' or 'benefits no longer obtained' into a specific analysis by inserting item identifications and data within the cell ranges set aside for that category. This will speed up the work considerably.

18.4.2 Multi-column spreadsheets

Spreadsheets really come into their own when you must link together a number of component analyses, and when there are cross-links between the various parts of the analysis. This will be necessary, for example, in an analysis of methods of improving reproductive performance in a beef enterprise, where the increased calving rate in one year will affect the number of heifer replacements available two years later, and the age distribution of cows in later years.

To represent an analysis of this type, it is necessary to have at least one column for each year, and commonly to have a summary column which shows a cost-benefit analysis of the gains of implementing the reproductive program, in comparison with no action. In this case, the spreadsheet makes it easy to discount costs and benefits as required in a cost-benefit analysis, since the discounting procedure is a built-in function.

For extension purposes, a series of these spreadsheets can be constructed for different districts within the region, using the same worksheet template but varying the data and some of the formulae to express differences between districts. The outcome for each year within each district analysis can then be automatically transferred into a linked regional spreadsheet to produce a summary of expected benefits across the region. Any costs incurred at the regional level can then be subtracted to produce a final overall cost-benefit ratio and net present value of the program. This was done, for example, in a regional analysis of a parasite control program in villages in Thailand (Meemark & Morris, 1989). Changing one variable at the farm or village level in such an analysis will immediately cause the entire analysis to be recalculated. It is also possible to link the district worksheets so that a change in certain variables (such as product and input prices) in the worksheet for district 1 will automatically transfer to all other districts, while figures such as calving rates are kept distinct.

18.4.3 Spreadsheet notebooks and three-dimensional spreadsheets

It is often useful to work with a group of spreadsheets which carry out related analyses with different sets of assumptions. The leading spreadsheets offer systems for combining a group of spreadsheets as pages in an electronic notebook, so that they can be worked on together very easily.

18.5 Spreadsheet models with risk considerations

Computer models have been used extensively to analyse disease control problems. Often these models are written in a computer language such as Turbo Pascal, and knowledge of such a language is a prerequisite for writing the program. It is possible now to construct moderately complex models purely within electronic spreadsheets, thus allowing people with very limited programming ability to produce models which are dynamic, ie, they represent changes in a system through time, in an iterative fashion. Some spreadsheet programs have special enhancements to assist in such advanced uses. Spreadsheet modelling is an excellent starting point in developing a model, since a functional version can be developed quickly, although if the model is to be used extensively it may be best transferred to a programming language once the full design has been worked out, mainly for gains in speed and ease of use.

The complicating factor in most mathematical models arises from chance or **stochastic elements**. The @RISK computer package is available as an add-in for Lotus 1-2-3, Excel and Symphony and brings advanced modelling and risk analysis to these worksheets (Palisade, 1992). In general, the technique in an @RISK analysis encompasses the following four steps, of which the first three can be supported.

1. Developing a model - by defining a problem or situation in the format of the spreadsheet package you are using.
2. Identifying risk - setting up the risky variables in the worksheet so that their possible values can be specified with probability distributions, and identifying the risky outcome variables in the worksheet results to be analysed.
3. Analysing the model with simulation using random numbers - to determine the range and probabilities of all possible outcomes for the results of the worksheet.
4. Making a decision - based on the results provided and personal preferences.

Probability distribution plays an important role in any analysis which incorporates risk. A probability distribution is a mathematical device for presenting the quantified risk for a variable. There are many forms and types of probability distributions available in @RISK, each of which describes a range of possible values and their likelihood of occurrence. There is a wide variety of distribution types ranging from uniform and triangular distributions to more complex forms such as gamma and Weibull (Figure 18.2).

In @RISK, all distribution types use a set of arguments to specify a range of actual values and distribution of probabilities, as can be seen in Figure 18.2. The normal distribution, for example, uses a mean and standard deviation as its arguments. The mean defines the value around which the bell curve will be centred and the standard deviation defines the spread of values around the mean. Over thirty types of distributions are available in @RISK for describing distributions for uncertain values in the worksheets.

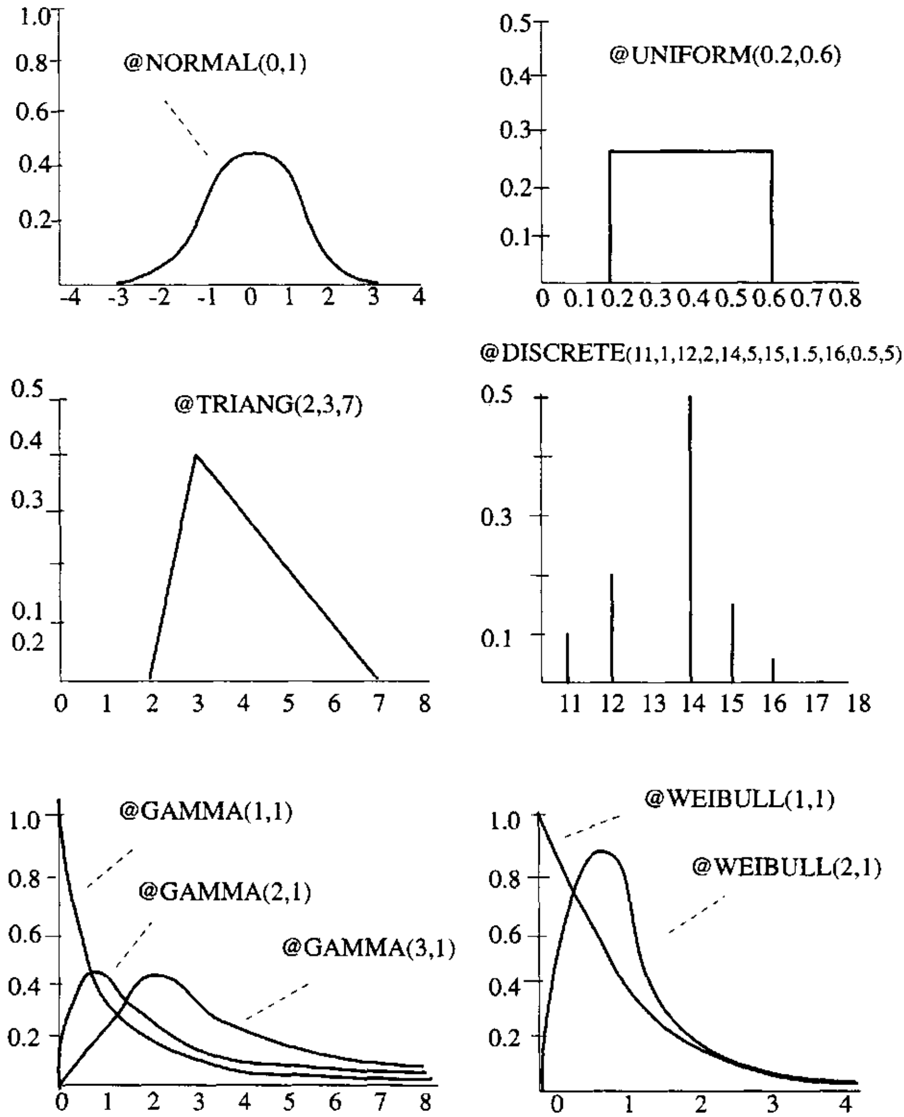

Figure 18.2 Example probability distribution graphs (normal, uniform, triangular, discrete, gamma and Weibull)

In @RISK, uncertain variables and cell values are entered as probability distribution @functions, for example: @TRIANG(A3/2.01,A4,A5), when you are using Lotus 1-2-3. This example is a triangular function with the minimum (actual value in cell A3 divided by 2.01), most likely (actual value in cell A4) and maximum (actual value in cell A5) value as arguments respectively. These @functions can be placed in the worksheet cells and formulae just like any other 1-2-3 @function.

Sampling is used in @RISK simulation to generate possible values from probability @functions. These sets of possible values are then used to evaluate the worksheet by sampling from the distributions perhaps 100 or 1000 times. Sampling is the process by which values are randomly drawn from input probability distributions. Because of this, sampling is the basis for the hundreds or thousands of repeated 'what-if' scenarios @RISK calculates for the worksheet. Each set of samples represents a possible combination of input values which could occur. Sampling in a simulation is done repetitively - with one sample drawn every iteration from each input probability distribution. With enough iterations, the sampled values for a probability distribution will become distributed in a manner which approximates the known input probability distribution. The statistics of the sampled distribution - mean, standard deviation and higher moments - will approximate the true statistics that were input for the distribution. It is not necessary to make every variable in the spreadsheet stochastic. Commonly this is limited to a small number of critical (ie, most important) variables.

The decision maker should recognize that analysis incorporating risk cannot guarantee that the action which is chosen to follow - even if skilfully chosen to suit the personal preferences - is the best action viewed from the perspective of hindsight. Hindsight implies perfect information, which is never available at the time the decision is made. The decision maker can be guaranteed, however, that (s)he has chosen the best personal strategy given the (imperfect) information that is available.

18.6 User-friendly spreadsheets

When the designer of a spreadsheet template is also the only user, layout is not a critical point in design, although it is wise to keep the structure uncluttered and easy to work with. Once a worksheet is distributed to others, it becomes just as important to produce a layout which is easy to use and error-resistant as it is to have all the calculations correct.

There are some important considerations in achieving this. Most worksheets which contain substantial calculations cannot be fitted into a single screen, so a new design structure is required. This should be based around programmed jumps from cell to cell. The worksheet is divided up into a series of single screens, such as Introduction, Data Entry, context-sensitive Help screens for various parts of the worksheet and Results. There will usually be quite a large number of cells required for intermediate calculations, which the typical user need never see.

A simple way of achieving this is to have blocks of cells, each comprising one screen-full, to display each of the major parts of the worksheet with which the user will want to interact - such as a data entry screen, one or more results screens, and an explanation screen for each area of the results. These screens should be easy to read and interpret, and automatic procedures should be used to jump from the current screen to the next one the user should see, once the user requests the jump. Blocks of screen area can be reserved for explanatory material which the user must read but should never alter. These blocks can be 'locked' so that the cursor cannot enter them in normal use.

Within blocks dedicated to data entry or calculation, subblocks should be laid out which contain closely related material which can be handled as a unit. For example, it may be necessary to add up rows 12 to 30 in column G. Instead of having to refer to each cell in the sequence by name in each formula as would be necessary if they were spread around, they can be handled as an inclusive block SUM (G12..G30) or similar.

Intermediate calculations should be stored in columns separated from the user-accessible ones sufficiently, so that the user is never aware of their existence in normal circumstances. This allows for ease of use but also allows the expert to check calculations easily. Annotation features in a spreadsheet or an add-in program allow explanatory notes to be attached to cells of a spreadsheet, mainly as an aide memoir to the logic on which a complex cell formula is based. This feature is extremely useful, since otherwise a formula that was quite clear six months ago becomes incomprehensible when reviewed, and may then be modified in a way which undermines the structure of the spreadsheet.

If any procedure must be carried out repeatedly in working with a spreadsheet, it is most efficient to program it in advance by writing a macro, a small program which most computer users can prepare. This carries out a specific set of steps within the spreadsheet, which may vary from something as simple as changing a font in a single step, to running a complex analysis by hitting one key.

The spreadsheets supplied with this book all work in accordance with these principles as much as possible, and use techniques such as macros. Not all features of each single spreadsheet program could be fully used, however, because the cases were designed such that they run in all 3 programs involved (ie, Excel, Quattro and Lotus).

18.7 Using the spreadsheet

Normally a well-designed template will take the user in a sequence of automated jumps through all the data entry stages, and after the last item has been entered it will automatically carry out its recalculation and position the cursor at the first result screen. Recalculation can however either be made automatic or be made to await a user instruction. One small problem with automated spreadsheets is that an error which is recognized after a data entry point is past cannot be corrected without repeating the run.

For a very polished spreadsheet, this can be overcome by copying each data item to a check screen just before calculation commences, where the user is given a chance to review the items entered and to loop back to correct any specific errors. After confirming the accuracy of the values, calculation will commence.

One major use of a spreadsheet is to compare the effect of some potential improvement with a 'base' analysis representing the status quo. In simple analyses this must be done by printing the result screen for the base analysis and then running the alternative and printing that to allow a comparison of the two. An advanced alternative is to allow the result screens to show two sets of figures, one for the base analysis and one for the alternative. The base analysis can either be repeated each time a comparison is done, or be processed separately and merely stored visually in the result screens to remind the user of the baseline values against which the alternative should be compared. Printed copies will contain both values.

An important part of an economic appraisal is **sensitivity analysis**, where the most influential biological and price variables in the analysis are each varied to test how susceptible the predicted financial return is to differences between estimated and actual items in the analysis, and variation which can be expected over time in major variables such as product price. The limits within which sensitivity analysis is conducted are a matter of choice to fairly represent the field situation. With regard to prices, the long-run range of lowest to highest may be taken (perhaps adjusted to current year equivalence), or else fixed percentage variation may be taken (say 10 and 20% above and below current values). With regard to biological variation in measured variables such as growth rate or pregnancy rate, sensitivity analysis may either be taken at 1 and 2 standard deviations from the measured sample mean, or again be allowed to vary by a percentage of the mean value. It is good practice to consider the mean or expected value and two levels of variation above and below the mean, thus requiring five calculations in total.

Spreadsheets really come into their own in sensitivity analysis, because what would otherwise have been a tedious process of repeating the entire calculation becomes a simple matter of changing one or more variables and viewing the result. It even becomes possible to adjust two variables at once (say product price and growth rate response) to produce a bivariate response surface, something which is far too cumbersome by hand because 25 evaluations are required for a single sensitivity analysis. If desired, the 25 results can be stored and then graphed in a 3-dimensional representation of a response surface within the same program.

18.8 Examples of the use of spreadsheets in practice

There are numerous spreadsheet templates of veterinary economic calculations available, either through distribution from the developer or through publication of the procedure in a scientific journal. Examples at the basic level include Quek *et al.* (1986), and Gulbenkian & Viegas (1988). Dijkhuizen *et al.* (1986) provide a much more extensive analysis system using a spreadsheet to analyse sow replacement economics, embodying most of the principles outlined. Carpenter (1988a,b) demonstrates the use of a spreadsheet in epidemiological modelling. Numerous other veterinary examples of spreadsheets exist in both epidemiology and economics.

In practice some very complicated simulation models with many interacting demands and services have been used. Whole sections of an organization have been simulated. The limits are only the capacity of the computer and the time taken to work and test the program. Much of the work has been facilitated by devising special computer simulation languages such as @RISK. Quantitative analysis techniques have gained a great deal of popularity with decision makers and analysts in recent years. Unfortunately, many people have mistakenly assumed that these techniques are magic black boxes that unequivocally arrive at the correct answer or decision. No technique, including those used by @RISK, can make that claim. These techniques are tools that can be used to help make decisions and arrive at solutions. Like any tool, they can be used to good advantage by skilled practitioners, but should never be used as a replacement for personal judgment.

References

Anderson, N., Morris, R.S. & McTaggart, I.K., 1976. Analysis of two schemes for the anthelmintic control of helminthiasis in weaned lambs. Australian Veterinary Journal 52: 174-180.

Carpenter, T.E., 1988a. Stochastic epidemiologic modeling using a microcomputer spreadsheet package. Preventive Veterinary Medicine 5: 159-168.

Carpenter, T.E., 1988b. Microcomputer programs for Markov and modified Markov chain disease models. Preventive Veterinary Medicine 5: 169-179.

Dijkhuizen, A.A., Morris, R.S. & Morrow, M., 1986. Economic optimization of culling strategies in swine breeding herds, using the 'Porkchop' Computer Program. Preventive Veterinary Medicine 4: 341-353.

Gulbenkian, M. & Viegas, F.J.T., 1988. OVISERRA: A computerized herd management system for dairy ewes. Acta Veterinaria Scandinavica, Supplementum 84, p. 530.

Meemark, N. & Morris, R.S., 1989. Economic analysis of the benefits of the Basic Animal Health Service. Proceedings International Seminar on animal health and production services for village livestock, Khon Kaen, Thailand, August 1989: 465-477.

Palisade, 1992. @RISK Users Guide, Risk analysis and simulation add-in for Lotus 1-2-3, Palisade Corporation, 31 Decker Rd, Newfield, NY 14867, 374 pp.

Quek, K.L., Ng, C.Y. & Chang, C.F., 1986. PigMoney: Application of electronic spreadsheet in the economics of pig production. Proceedings 4th International Symposium on Veterinary Epidemiology and Economics, Singapore, 1985: 256-257.

19

Computer excercises on animal health economics

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Supervision:
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This chapter includes a printout of the computer excercises developed for use in the spreadsheet programs Lotus 1-2-3 and Quattro Pro for Dos and Excel for Windows.
To start the excercises follow the instructions supplied with the diskette.

```
=================================================================
          COMPUTER EXERCISES ON ANIMAL HEALTH ECONOMICS
                 = Principles and Applications =
                  Version 2.0 - September 1995
=================================================================

INTRODUCTION                       (Current file: INTROAHE.WK1)

This introductory worksheet provides information on the computer
exercises in general and on the different cases in particular.

=================================================================
Design:               C.W. Rougoor & A.W. Jalvingh
Supervisors:          A.A. Dijkhuizen, R.S. Morris & R.B.M. Huirne
(c) Copyright:
          Wageningen Agricultural University
          Department of Farm Management
          Hollandseweg 1
          NL-6706 KN Wageningen
                                                        Press PgDn
About the computer exercises on animal health economics
=================================================================

Each exercise is available as a separate file (worksheet format)
that can be opened in the spreadsheet of your choice.

The files with the exercises can be found in the directory C:\AHE
when you have used the automatic installation procedure. In case of
manual installation, the files are in the directory of your choice.

The exercises have been made up in a way that one page has 20 lines.
In case you see more or fewer than 20 lines on your screen, you should
change the settings of your spreadsheet. How this can be done depends
on the spreadsheet you are using.

In certain spreadsheets you can open more than one worksheet at a
time. In that case you can easily switch between the exercises and
this introductory text.

                                                        Press PgDn
Available files
=================================================================
Basic methods:
PRFUNCT1.WK1         Production Function
PRFUNCT2.WK1         Production Function (extra exercise)
PARTBUD.WK1          Partial Budgeting
COSTBEN.WK1          Cost-Benefit Analysis

Advanced methods:
LINPROG.WK1          Linear Programming
DYNPROG.WK1          Dynamic Programming
MARKOV.WK1           Markov Chain Simulation

Decision analysis of risky choices:
MONTCAR.WK1          Monte Carlo Simulation
DECANAL.WK1          Decision Analysis
DECTREE              Decision-Tree Analysis (not a spreadsheet exercise!)

Continue by opening the file of your choice. Below you can find more
information on each exercise.                           Press PgDn
```

```
More information on exercises
======================================================================
Name of file:       PRFUNCT1.WK1        Production Function
Title of case:      Farm advisory case
Purpose:    1. Understanding the principles of a production function.
            2. Determining the optimal level of veterinary services
               at a sow farm.
Keywords:   Variable costs, fixed costs, production function,
            marginal and average costs and returns.
Time:       Approximately 30 min necessary for the main exercise.
            Another 15 min for the (optional) sensitivity analysis.

Name of file:       PRFUNCT2.WK1        Production Function
Title of case:      Helminthic case: an experimental example
Purpose:    1. Understanding the principles of a production function.
            2. Example of a production function with real data.
Keywords:   Variable costs, fixed costs, production function,
            marginal and average costs and returns.
Time:       30 min for the entire case.
                                                              Press PgDn
Name of file:       PARTBUD.WK1         Partial Budgeting
Title of case:      Caesarean section in dairy cattle
Purpose:    1. Understanding the principles of partial budgeting.
            2. Calculating the costs of caesarean section in cattle.
Keywords:   Static, additional returns, reduced costs, returns foregone,
            extra costs.
Time:       Approximately 20 min necessary for the main exercise.
            Another 10 min for the (optional) sensitivity analysis.

Name of file:       COSTBEN.WK1         Cost-Benefit Analysis
Title of case:      Enzootic bovine leucosis
Purpose:   1. Understanding the principles of cost-benefit analysis.
           2. Comparing 2 strategies to eradicate enzootic bovine
              leucosis.
Keywords:   Dynamic, real interest rate, net present value, benefit-cost
            ratio, internal rate of return.
Time:       Approximately 30 min for the main exercise, including 10
            min for the optional calculations with real interest rate.

                                                              Press PgDn
Name of file:       LINPROG.WK1         Linear Programming
Title of case:      Cows and/or sheep
Purpose:    1. Understanding the principles of linear programming.
            2. Finding the economically best combination of keeping cows
               and/or sheep, taking two constraints into account.
Keywords:   Static, constraints, objective function, optimization.
Time:       Approximately 30 min for the basic principles. Another
            10 min for carrying out the (optional) sensitivity analysis.

Name of file:       DYNPROG.WK1         Dynamic Programming
Title of case:      Sow replacement
Purpose:    1. Understanding the principles of dynamic programming.
            2. Finding the economically best moment of replacing a sow.
Keywords:   Dynamic, stage, state, optimization, retention pay-off (RPO)
Time:       Approximately 30 min for the basic principles, after that
            another 5 min for calculating the RPO and/or 10 min for a
            sensitivity analysis.


                                                              Press PgDn
```

```
Name of file:       MARKOV.WK1          Markov Chain Simulation
Title of case:      (A) Pneumonia in sheep
                    (B) Mastitis in dairy cattle
Purpose:    1. (ad A) Understanding the principles of a Markov chain.
            2. (ad B) Comparing different strategies for treating mastitis
               to find the economically best one.
Keywords:   Dynamic, transition matrix, state, vector, stable situation.
Time:       (A) will take about 15 min. The first part of (B) takes
            15 min. The second part (optional; dynamic transition rates)
            takes another 15 min.

Name of file:       MONTCAR.WK1         Monte Carlo Simulation
Title of case:      Aujeszky's disease in swine
Purpose:    1. Understanding Monte Carlo simulation.
            2. Simulating the number of animals infected with Aujeszky's
               disease in a herd and its financial effect over time.
Keywords:   Dynamic, random sampling, simulation.
Time:       Approximately 30 min for the main exercise. Another 10 min
            for the optional exercise (different initial situation).
                                                            Press PgDn
Name of file:       DECANAL.WK1         Decision Analysis
Title of case:      Left-displaced abomasum in cattle
Purpose:    Comparing different strategies to treat displaced
            abomasum, taking risk into account.
Keywords:   Static, expected monetary value, maximin, minimax, maximax,
            utility, Bayes' theorem, value of information.
Time:       Total time necessary 60 min, including 15 min for utility,
            and 20 min for value of information. Both are optional.

Name of file:       DECTREE             Decision-Tree Analysis
Title of case:      Left-displaced abomasum in cattle
Purpose:    1. Understanding the principles of building a decision tree.
            2. Comparing strategies, taking into account probabilities of
               success and failure.
Keywords:   Decision tree, probabilities, expected monetary value
Time:       Total time necessary about 40 min.
NOTE: This exercise does not take place in a spreadsheet, but uses the
program SMLTREE. If you have the program available, start it and use
the file DECTREE for the exercise. The questions that go with the
exercise can be found in the book.                          Press PgDn
======================================================================

END OF INTRODUCTION

Continue by opening the exercise (= file) of your choice in
the spreadsheet.

======================================================================
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Supervisors:        A.A. Dijkhuizen, R.S. Morris & R.B.M. Huirne
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         Hollandseweg 1
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Current exercise: PRFUNCT1.WK1 Production Function
Title of case: Farm advisory case

Purpose: 1. Understanding the principles of a production function.
2. Determining the optimal level of veterinary services at a sow farm.
Keywords: Variable costs, fixed costs, production function, marginal and average costs and returns.
Time: Approximately 30 min necessary for the main exercise.
Another 15 min for the (optional) sensitivity analysis.

Press PgDn

PRODUCTION FUNCTION

"Farm Advisory Case"

A pig farmer wants to increase the number of pigs weaned per sow per year. (S)he asks a veterinarian for help. The veterinarian tells him/her that it is possible to participate in a herd health program, which includes that the veterinarian will visit the farm regularly to check the herd and to give advice. The results depend on the number of visits per year. The farmer can choose how many veterinary visits (s)he prefers.

After you have finished a page, you can continue by pressing PgDn.

Experience in the past showed an effect on pigs weaned per sow per year as stated below:

no. of visits per year	pigs weaned per sow per year
0	18.00
5	18.30
10	18.80
15	19.50
20	20.10
25	20.50
30	20.80
35	21.00
40	21.10

The above scheme is usually called production function. In the graphical representation of this function, the input of visits is placed on the X-axis and the piglet output on the Y-axis.

Press PgDn

Let us have a look at this graph. Excel-user: Press <CTRL> G; Lotus-user: Press <ALT> G and Quattro Pro-user: Press <ALT> P. Pressing any key will bring you back to this screen.

The costs of the herd health program, of course, depend on the number of visits per year (the variable costs). There are also some fixed veterinary costs, independent of whether or not the farm participates in the herd health program: medicine costs etc.

Variable costs per visit (US$)	120
Fixed veterinary costs per year (US$)	1500

The counterbalance of these costs is the net returns from more pigs weaned per sow per year.

Net returns from 1 extra piglet (US$)	30
Number of sows on the farm	100

Press PgDn

All these additional costs and returns have to be taken into account to calculate the net revenue of the herd health program.

Calculate the total returns from the extra piglets and the total veterinary costs if the veterinarian visits the farm 20 times per year.

(If necessary, go back to the previous screen by pressing "PgUp")

You can fill in the answer after positioning the cursor in the right cell (Cell E94 and E95; use the arrow keys or the mouse):

	US$	
Total veterinary costs:		(1)
Total returns extra piglets:		(2)

Press PgDn

The table below gives the total extra piglets per farm, the total variable costs (TVC), the total returns (TR) from these extra piglets, and the marginal returns (MR).

no. of visits	extra piglets	TVC ($/farm)	MC ($/ piglet)	TR ($/farm)	MR ($/piglet)
0	0	0			
5	30	600		900	30
10	80	1200		2400	30
15	150	1800		4500	30
20	210	2400		6300	30
25	250	3000		7500	30
30	280	3600		8400	30
35	300	4200		9000	30
40	310	4800		9300	30

Press PgDn

The farmer now has to decide what to do: does (s)he want to participate in the herd health program? And if so: how many visits per year should be opted for?

To make this decision, we need to calculate the marginal costs (MC). The marginal costs are the additional costs made to get one extra piglet per farm.

Calculate these costs (or: fill in a formula that calculates them for you!) for 5 and 10 visits per year. You can fill them in the table on the previous screen.

Return to that screen by pressing PgUp

Did you calculate and fill in the marginal costs already?

No? Press PgUp twice to go to the table where you can enter the marginal costs for 5 and 10 visits.

Yes? Press PgDn

If you have done it correctly you will have found the following values. The average variable costs (AVC) are also given. These values are used to make a graph of the marginal and average costs and returns (Excel-user: press <CTRL> M, Lotus-user: <ALT> M, QPRO-user: <ALT> N).
Look at the graph and decide what the farmer should do.

no. of visits	extra piglets	TVC ($/farm)	AVC ($ /piglet)	MC ($ /piglet)	TR ($/farm)	MR $/piglet)
0	0	0				
5	30	600	20.00	20.00	900	30
10	80	1200	15.00	12.00	2400	30
15	150	1800	12.00	8.57	4500	30
20	210	2400	11.43	10.00	6300	30
25	250	3000	12.00	15.00	7500	30
30	280	3600	12.86	20.00	8400	30
35	300	4200	14.00	30.00	9000	30
40	310	4800	15.48	60.00	9300	30

Press PgDn

How many visits per year are optimal?
You can enter your answer in F183:

SENSITIVITY ANALYSES (optional, 15 min)

What is the optimal decision when the variable costs of a veterinary visit are US$180 instead of US$120? You can answer this question by changing the value in cell F71. The results will be recalculated automatically. Walk through the pages by pressing "PgUp" and "PgDn".

Number of visits per year (fill in F196):

Press PgDn

Because of a decreasing demand for piglets, the price the farmer can make for a piglet next year is expected to be lower than this year. The farmer is wondering whether it is still profitable next year to participate in the herd health program. We are interested in the break-even point. The break-even point is the point where participating in the program is neither favourable nor unfavourable. This means that the marginal returns of the program will always be lower than, or equal to the average costs. Find the value for the net returns from 1 extra piglet where this is true (You first have to change the price of a veterinary visit back to US$120).
Answer in cell F212 (2 decimal places):

Press PgDn

Change the net returns from 1 extra piglet (in cell F77) to the value you have just calculated and have a look at the marginal and average cost functions (by pressing <CTRL> M, <ALT> M or <ALT> N).

If you have done this correctly, you can see that in this situation the average costs are always higher than, or equal to, the marginal returns!

Press PgDn

```
      A         B         C         D         E         F         G         H
241 ======================================================================
242 You have finished the current exercise.
243 You can now choose to:
244 - continue with an extra exercise on production function by opening
245   the file 'PRFUNCT2.WK1'
246 - return to the introductory file by opening the file 'INTROAHE.WK1'
247 - quit the computer exercises by closing the spreadsheet
248
249 ======================================================================
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255 Supervisors:       A.A. Dijkhuizen, R.S. Morris & R.B.M. Huirne
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COMPUTER EXERCISES ON ANIMAL HEALTH ECONOMICS
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==

Current exercise: PRFUNCT2.WK1 Production Function
Title of case: Helminthic case: an experimental example

==

Purpose: 1. Understanding the principles of a production function.
2. Example of a production function with real data.
Keywords: Variable costs, fixed costs, production function, marginal and average costs and returns.
Time: 30 min for the entire case.

==

Press PgDn

HELMINTHIC CASE: AN EXPERIMENTAL EXAMPLE

In reality it is difficult to get all data for a detailed description of a production function, because you need data from many input levels. In this case the financial returns from three anthelmintic schemes were compared with 'no treatment' (treatment 0) in groups of Corriedale ewes using real data from a field experiment.

The three treatment schemes were:
1. Pre- and post-lambing treatment (treatment I);
2. Critical treatment: one treatment in early summer and a second one in mid-summer (treatment II);
3. Biweekly treatment: treatment each fortnight to ensure minimum levels of infection (treatment III).

Press PgDn

Although the treatments do not represent an evenly graded series of steps in investment, they do represent a graded set of levels of parasite control from zero to extremely effective.

Among other things, the wool cut per ewe (kg) and the mean weight of the lambs (kg) were measured, which gave the following results:

Treatment	Wool	Weight
0	3.00	19.80
I	3.06	21.80
II	3.60	22.70
III	3.78	22.70

'Wool cut per ewe' is used to make a graph of the production function. The treatment input is placed on the X-axis and the wool output on the Y-axis. There is no line drawn between the points, because a line would suggest a continuous scale on the X-axis. Excel-user: Press <CTRL> G, Lotus-user: Press <ALT> G, and Quattro Pro-user: Press <ALT> F. You can return to this screen just by pressing any key.

Press PgDn

The difference in the amount of wool, from the lambs and from the ewes, results in a difference in returns from the four helminth control schemes. The following table shows costs and returns (in US$) adjusted to a standard flock of 100 sheep:

EWES and LAMBS		TREATMENT 0	I	II	III
Returns:	Wool	774	815	969	1006
	Ewes	353	412	360	380
	Lambs	215	239	288	266
RETURNS		1342	1466	1617	1652
Costs:	Anthelmintic and labour	0	21	21	220
RETURNS - COSTS		1342	1445	1596	1432

Press PgDn

To find the optimal treatment, we have to calculate the marginal costs and returns.

What are the marginal costs of treatment I and the marginal returns from treatment III? We already calculated the other marginal costs and returns for you. Fill in the missing two numbers (as a value or as a difference between spreadsheet cells):

	0	I	II	III
Marginal Costs	0		0	199
Marginal Returns	0	124	151	

Press PgDn

The X-axis of the production function you made before is not a continuous scale. Therefore it is not possible to find an optimal point on the X-axis where the marginal costs are equal to the marginal returns. But we can find out which treatment is 'one step too far', ie, where the marginal costs exceed the marginal returns.

Which treatment is the best from an economic point of view?

0, I, II or III? Enter your answer in cell G110:

Press PgDn for a sensitivity analysis on these results.

```
SENSITIVITY ANALYSIS

Prices used to value wool were those ruling at auction. These values
were the highest values obtained over 5 years. The minimum price level
of wool in the past 5 years was only 27% of the present level.

Calculate the returns from wool with this minimum price level (Cells
D69 to G69). Does this change your conclusion about the economically
best treatment?
Which treatment is the best: 0, I, II or III?
                              Answer in cell G132:  [          ]






                                                            Press PgDn

======================================================================

You have finished the current exercise.
You can now choose to:
- return to the introductory file by opening the file 'INTROAHE.WK1'
- quit the computer exercises by closing the spreadsheet

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        A       B       C       D       E       F       G       H
 1 ==================================================================
 2             COMPUTER EXERCISES ON ANIMAL HEALTH ECONOMICS
 3                   = Principles and Applications =
 4                     Version 2.0 - September 1995
 5 ==================================================================
 6 Current exercise: PARTBUD.WK1     Partial Budgeting
 7 Title of case:    Caesarean section in dairy cattle
 8 ==================================================================
 9 Purpose:  1. Understanding the principles of partial budgeting.
10           2. Calculating the costs of caesarean section in cattle.
11 Keywords: Static, additional returns, reduced costs, returns foregone,
12           extra costs.
13 Time:     Approximately 20 min necessary for the main exercise.
14           Another 10 min for the (optional) sensitivity analysis.
15 ==================================================================
16
17
18
19
20                                                      Press PgDn
21
22           PARTIAL BUDGETING: CAESAREAN SECTION CASE
23
24 To determine the additional costs of and returns from caesarean sections
25 in dairy cattle, a partial budgeting approach was used.
26
27 A partial budgeting model divides the costs and benefits into
28 different groups:
29                    1. Additional Returns
30                    2. Reduced Costs
31                    3. Returns Foregone
32                    4. Extra Costs
33
34
35 The costs and benefits of a caesarean section include the effects
36 as stated on the next page.
37
38                                                      Press PgDn
39
40
41
42 Effects of caesarean section:
43
44           1. costs of surgery                    [        ]
45           2. drop in milk production
46                    A. less milk                  [        ]
47                    B. less feed necessary        [        ]
48           3. heavier weights of calves           [        ]
49           4. 20% increase in culling rate        [        ]
50
51 Enter in rows F44 and F46 to F49 1, 2, 3, or 4 to indicate to which
52 partial budgeting category, as defined on the previous page, you think
53 that effect belongs.
54
55
56
57 Now we will deal with the different categories one by one.
58
59                                                      Press PgDn
60
```

A	B	C	D	E	F	G	H

1. ADDITIONAL RETURNS

The average weight for female calves is 40 kg, for male calves 43 kg. Calves delivered by caesarean section are on average 3.5 kg heavier. 82% of the calves born by caesarean section are male calves. Calf mortality increases to 12%, compared with 5% in a normal situation. The prices per kg of body weight for calves are:

female calves (US$) 4
male calves (US$) 6

Calculate the average returns from a calf born by caesarean section.

Enter your answer in cell E74:

Press PgDn

This table gives the average returns for caesarean section calves and for calves from a normal delivery:

	Normal female	Normal male	Caesarean section female	Caesarean section male
Weight	40	43	43.5	46.5
Price	4	6	4	6
% animals	50	50	18	82
% mortality	5	5	12	12
Returns	76.00	122.55	27.56	201.33
Sum		198.55		228.89

The additional returns are the difference between these two:
Additional returns: sum(C-section) - sum(Normal) = 30.34

Press "PgDn" for the calculation of the reduced costs.

2. REDUCED COSTS

After a caesarean section there is a drop in milk production, resulting in a saving in concentrates:

Decrease in milk production: 70 kg
Decrease in concentrates: 0.5 kg/kg of milk
The price of concentrates: 0.20 US$/kg

Calculate the reduced costs due to caesarean section.

Enter your answer in cell G112 (2 decimal places):

Press PgDn

```
   |    A    |    B    |    C    |    D    |    E    |    F    |    G    |  H
121
122 3. RETURNS FOREGONE
123
124 We will give you the value of 'returns foregone':
125 Milk losses after caesarean section are 70 kg on average.
126 The price of one kilogram of milk:          0.40  US$
127 Returns foregone: kg milk x milk price =                        28.00
128
129 4. EXTRA COSTS
130                                                   US$
131 Cost of surgery:                                150.00
132 Culling: Assume the costs of one animal culled
133 to be US$340. The culling rate increases by
134 20 percentage points (e.g. from 30 to 50%).
135 What are the costs? (answer in F135)           [        ]
136
137
138          Extra costs: surgery + culling =                      150.00
139                                                           Press PgDn
140
141
142 Now we have calculated the values for the different categories:
143
144          1. ADDITIONAL RETURNS                                  30.34
145          2. REDUCED COSTS
146          3. RETURNS FOREGONE                                    28.00
147          4. EXTRA COSTS                                        150.00
148                                                           ----------
149 NET RETURNS (1.) + (2.) - (3.) - (4.)                         -147.66
150
151 Is caesarean section profitable from an economic point of view?
152 Y(es) or N(o)? (cell D152): [        ]
153
154 SENSITIVITY ANALYSIS (optional, 10 min)
155
156 Assume that owing to a change in agricultural policy in the
157 country, the price a farmer can make for the milk decreases to
158 US$0.15. However, the demand for calves increases. This results
159 in a price per kg of body weight that is twice the present price.
160                                                           Press PgDn
161
162 Does this change your conclusion about the profitability of
163 caesarean section? Y(es) or N(o)? (Change the values of cells E126,
164 D69 and D70, answer in cell G164):                        [        ]
165
166
167
168 Will caesarean section ever be more profitable than a normal delivery
169 (with the given price levels), when we assume that caesarean section
170 does not have any negative effects on calf survival rate, percentage
171 of animals kept in the herd, and milk production?
172
173 Enter your answer in G173 (Y(es) or N(o)):                [        ]
174
175
176
177
178
179                                                           Press PgDn
180
```

	A	B	C	D	E	F	G	H
181	===							
182								
183	You have finished the current exercise.							
184	You can now choose to:							
185	- return to the introductory file by opening the file 'INTROAHE.WK1'							
186	- quit the computer exercises by closing the spreadsheet							
187								
188	===							
189		COMPUTER EXERCISES ON ANIMAL HEALTH ECONOMICS						
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COMPUTER EXERCISES ON ANIMAL HEALTH ECONOMICS

= Principles and Applications =

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Current exercise: COSTBEN.WK1 Cost-Benefit Analysis

Title of case: Enzootic bovine leucosis

Purpose: 1. Understanding the principles of cost-benefit analysis.
2. Comparing 2 strategies to eradicate enzootic bovine leucosis.

Keywords: Dynamic, real interest rate, net present value, benefit-cost ratio, internal rate of return.

Time: Approximately 30 min for the main exercise, including 10 min for the optional calculations with real interest rate.

Press PgDn

COST-BENEFIT ANALYSIS: ENZOOTIC BOVINE LEUCOSIS CASE

Suppose 2 strategies A and B are available to eradicate enzootic bovine leucosis in cattle in a particular area. Costs due to the disease are production losses.
The benefits of an eradication program are the total of expected losses that are avoided. The costs are those invested in the program. We suppose that the costs and benefits occur at the end of each year.

A calculation is necessary to know which strategy is the most favourable from an economic point of view.

Press PgDn

The costs and benefits of the 2 strategies are:

	Strategy A		Strategy B	
Year	Costs	Benefits	Costs	Benefits
1	20	0	2	1
2	10	8	2	3
3	7	14	4	6
4	4	18	5	7
5	0	23	6	14

Real interest rate 5 %

The real interest rate is used to calculate the discount factor, which is needed to determine the present value of future costs and benefits.

Press PgDn

A	B	C	D	E	F	G	H

Calculate the discount factor that is necessary to calculate the present value of the costs and benefits of years 1 and 2. Use the given interest rate (Give your answer in 2 decimal places):

Discount factor year 1 (cell F66): [ ] (1)
Discount factor year 2 (cell F67): [ ] (2)

If you want to practise calculating the discount factor a bit more, press F5. Excel-user: type "Q21", Lotus- and Quattro Pro-user: type "K21" and press Enter.
The table on the next page gives the discount factors and the net present value of the costs and benefits for years 1 to 5 for both strategies.

Press PgDn

PRESENT VALUES

Year	Discount factor	Strategy A Costs	Strategy A Benefits	Strategy B Costs	Strategy B Benefits
1	0.95	19.05	0.00	1.90	0.95
2	0.91	9.07	7.26	1.81	2.72
3	0.86	6.05	12.09	3.46	5.18
4	0.82	3.29	14.81	4.11	5.76
5	0.78	0.00	18.02	4.70	10.97
Total		37.46	52.18	15.99	25.58

These values are used to calculate the different criteria. Calculate the Net Present Value (NPV) of strategy B and the B/C ratio of strategy A. Answer in cell F97 and cell C98 (2 decimal places):

	Strategy A	Strategy B
Net Present Value	14.72	[ ]
Benefit-Cost Ratio	[ ]	1.60
IRR approximation	23.90	>=80

Press PgDn

Which strategy would you advise based on the NPV?
Strategy A or B? (cell F103) [ ]

Which strategy would you advise based on the B/C ratio?
Strategy A or B? (cell F108) [ ]

Consider the following statement and say whether it is T(rue) or F(alse) (answer in F116):
When the objective of the eradication program is to get as much money back for every dollar invested in it, the Net Present Value is the best selection criterion. [ ]

Press PgDn

```
   |    A    |    B    |    C    |    D    |    E    |    F    |    G    |  H  |
121
122 At what real interest rate are the benefits equal to the costs for
123 strategy A? You can check your answer by filling in that real
124 interest rate in the previous calculation!
125
126
127 SENSITIVITY ANALYSIS
128
129 The real interest rate increases. This will have a different effect
130 on the NPV and the B/C-ratio of both strategies.
131
132 You can see this effect by using a real interest rate of 14%.
133 Which strategy would you advise now?
134           Strategy A or B? (cell F134)          [          ]
135
136
137
138
139                                                             Press PgDn
140
141 ==================================================================
142
143 You have finished the current exercise.
144 You can now choose to:
145 - return to the introductory file by opening the file 'INTROAHE.WK1'
146 - quit the computer exercises by closing the spreadsheet
147
148 ==================================================================
149           COMPUTER EXERCISES ON ANIMAL HEALTH ECONOMICS
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154 Supervisors:        A.A. Dijkhuizen, R.S. Morris & R.B.M. Huirne
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159           NL-6706 KN Wageningen
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K L M N O P Q R

CALCULATIONS WITH THE REAL INTEREST RATE

A benefit of US$100 to be obtained in one year has less value today than a benefit of US$100 received immediately, because of interest yields. Future costs and benefits, therefore, should be discounted, resulting in their present value.
In the estimated costs and benefits over the different years, inflation is usually not taken into account. Therefore, inflation should not be included in the interest rate either. This value, the real interest rate, is lower than the normal interest rate, and often more stable.
For every year and real interest rate a discount factor can be calculated. This factor is 1/(1+real interest rate/100) for costs and benefits received in year 1.

Calculate the discount factor for a real interest ate of 9% for year 1. (Answer in cell P37, with 2 decimals)

Press PgDn for more examples.

Use the calculated discount factor to calculate the present value of US$725 to be obtained in year 1.
(Answer in cell P44, no decimals)

The formula for calculating the discount factor for more than one year is when 'n' is the number of years and 'i' is the real interest rate: discount factor = 1/(1 + i/100)^n.

Calculate the present value of receiving (for sure) US$200 each year over the first 4 years, when the real interest rate is 6%. (Start with calculating the discount factors for years 1 to 4).

Present value (cell P56, no decimals):

Press PgDn

Let us try it the other way around:
The present value of US$25 you will get in two years is US$ 23.11.

What is the real interest rate? (cell P66)

Return to the main exercise by pressing F5 and:

Excel-user: type "A80"
Lotus- and Quattro Pro-user: type "A61".

==

COMPUTER EXERCISES ON ANIMAL HEALTH ECONOMICS
= Principles and Applications =
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==

Current exercise: LINPROG.WK1 Linear Programming
Title of case: Cows and/or sheep

==

Purpose: 1. Understanding the principles of linear programming.
2. Finding the economically best combination of keeping cows and/or sheep, taking two constraints into account.

Keywords: Static, constraints, objective function, optimization.

Time: Approximately 30 min for the basic principles. Another 10 min for carrying out the (optional) sensitivity analysis.

==

Press PgDn

LINEAR PROGRAMMING: COWS AND/OR SHEEP CASE

A farmer has got cows (X), but is thinking of buying some sheep (Y) also; it might be profitable. (S)he has to take into account the limited amount of grass and labour (s)he has available. This is an optimization problem that can be solved by linear programming.
As mentioned before, there are some constraints: labour and grass. There are 30 hectares of grass available. One hectare is sufficient for 2 cows or 5 sheep. The farmer likes his/her job, but is not a work-aholic. (S)he does not want to work more than 40 hours a week. One cow will cost 75 minutes (=1.25 hours) per week, a sheep will cost only 9 minutes per week.

We can write these constraints in a mathematical formulation:

$$a \times X + b \times Y <= c.$$

Press PgDn

Enter the missing values of a, b and c (mentioned in the formula) in the following table. Some of them have already been calculated for you:

Constraint	a	b	c
Labour (hrs)		0.15	
Grass (ha)	0.50		30

There is also the necessity to consider only nonnegative values for our variables X and Y. So:

$$X >= 0$$
$$Y >= 0 \quad (1)$$

Press PgDn

This is a problem with two variables (X and Y) so the problem can be represented graphically. Any 'action' (X, Y) is equivalent to a point with these coordinates in a standard two-dimensional plane. The constraints restrict the feasible actions to a region within this plane.

Have a look at the graph by pressing <CTRL> G (Excel), <ALT> G (Lotus) or <ALT> C (Quattro Pro). The lines you see are simply the constraint expressions replacing the inequality by an equality. Note that the constraints (1) restrict the region to the positive quadrant. Pressing any key will bring you back to this screen.
Which area shows the solutions that are feasible for these constraints? A, B, C or D? Answer in cell F74.

Press PgDn

Till now we have forgotten one limitation: the barn for the cows has space for only 40 cows. Does this influence the feasible area of the graph? Y(es) or N(o)? Answer in cell F84:

The farmer wants to maximize the total net returns (R). The net returns from cows and sheep are given in the following table:

Net returns (US$/year)

Cows	600
Sheep	100

So, one cow yields the same net returns as six sheep. In a mathematical formulation:

$$\max R = \max 600 \times X + 100 \times Y.$$

Press PgDn

The lines for R = 12000 and R = 14000 are plotted in the diagram of feasible actions. These lines give the relationship denoting equal net returns. Press <CTRL> R (Excel), <ALT> R (Lotus) or <ALT> D (Quattro Pro) to have a look at the graph.

Is the following statement T(rue) or F(alse)?

If an optimal solution exists, an optimal solution can always be found at an angular point of the feasible region of the problem.
Answer in cell D110:

The next step we have to take is calculating the (X,Y) values of these angular points. The feasible area has, in our situation, 4 angular points. One of them is (0,0), which is not interesting. Another one is the point where the 2 constraint lines cross. Besides these there are (0,Y) and (X,0). Here one of the constraints crosses the Y- and the X-axis respectively.

Press PgDn

The following table gives the X and Y values of the points where constraints cross each other or the Y- or X-axis. X(L) and Y(L) and X(G) and Y(G) are the values of X and Y for the labour and grass constraint respectively:

Angular Point	X	Y
Y(L)=Y(G)	20	100
(0,Y(L))	0	267
(0,Y(G))	0	150
(X(L),0)	32	0
(X(G),0)	60	0

Calculate the total net returns of the 3 feasible angular points. (You can have another look at the graph to find the 3 points). What number of cows and sheep is the best from an economic point of view?

Optimal number of cows (cell E136):

Optimal number of sheep (cell E137):

Press PgDn

The value of the objective function for the 3 feasible angular points:

Angular points	Returns
X=0	15000
Y=0	19200
Y(L)=Y(G)	22000

This results in the following optimal situation:

X = 20 cows
Y = 100 sheep

The basic situation is ready now. Let us use the model to do some sensitivity analyses.

Press PgDn

SENSITIVITY ANALYSES (optional, 10 min)

The farmer knows quite well the specific results of the cows on the farm. But the estimate of the net returns from the sheep is rather uncertain. Below what value should the farmer change the optimal strategy? The slope of the objective function line is determined by the ratio of the net returns. This ratio also determines which angular point is the optimal strategy.

At which slope is the objective function equal for (20 cows, 100 sheep) and (32 cows, no sheep)? A, B, C or D?

A. 2.50
B. 8.33 Answer in cell F174:
C. -2.50
D. -8.33

Press PgDn

A	B	C	D	E	F	G	H

Use this value to calculate the break-even point for the net returns
from sheep: For which value of the net return from sheep does the
optimal situation change to 'only cows' instead of 'sheep and cows'?
Answer in cell D185:

Also calculate the value of the net returns from sheep where the optimal
situation changes to 'only sheep' instead of 'sheep and cows'. (You
first have to find out what the slope of the objective function should
be in this situation.)
Answer in cell D194:

Press PgDn

===

You have finished the current exercise.
You can now choose to:
- return to the introductory file by opening the file 'INTROAHE.WK1'
- quit the computer exercises by closing the spreadsheet

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COMPUTER EXERCISES ON ANIMAL HEALTH ECONOMICS
= Principles and Applications =
Version 2.0 - September 1995

===

Design: C.W. Rougoor & A.W. Jalvingh
Supervisors: A.A. Dijkhuizen, R.S. Morris & R.B.M. Huirne

A	B	C	D	E	F	G	H	I	J

===

COMPUTER EXERCISES ON ANIMAL HEALTH ECONOMICS
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===

Current exercise: DYNPROG.WK1   Dynamic Programming
Title of case: Sow replacement

===

Purpose: 1. Understanding the principles of dynamic programming.
          2. Finding the economically best moment of replacing a sow.
Keywords: Dynamic, stage, state, optimization, retention pay-off (RPO)
Time: Approximately 30 min for the basic principles, after that another 5 min for calculating the RPO and/or 10 min for a sensitivity analysis.

===

Press PgDn

DYNAMIC PROGRAMMING: SOW REPLACEMENT CASE

Decisions to replace sows are usually based on economic rather than on biological considerations: the sow is not culled because she is no longer able to produce but because more is expected from a replacement sow.

A pig farmer in a specific area has some general ideas about the optimal sow replacement strategy. It is not based on calculation, just intuition. (S)he thinks calculation may be worthwhile!

To simplify the case, we say that a sow can be 4 parities old at the most. The returns from a sow depend on the parity she is in.

Press PgDn

The farmer keeps good records of the sows, so knows exactly what the typical results on the farm are for sows in each age category:

Parity	1	2	3	4
Gross Returns - feed costs (US$)	240	320	400	340
Slaughter value (US$)	180	190	210	195

Calculate the average gross returns minus feed costs per sow on the farm. Let us assume that there is no replacement: all sows are (voluntarily) replaced after parity 4 (answer in A54).

To optimize sow replacement decisions, we also need to know the purchase price of a young sow: 225 (US$).

Press PgDn

Calculate the profit for each parity, including the change in slaughter value of the sows. Enter your answers in the following table: we already calculated one for you!

Parity	1	2	3	4
Profit		330		

Replacement of sows can be seen as a sequence of decisions taken at a number of stages. Dynamic programming (DP) works from a certain point in time backwards (end of planning horizon) to the present. It requires so many steps in time that the starting point (somewhere in the future) does not influence your decision now. In this example, we use a planning horizon of 20 time steps. Press PgDn

In each parity the farmer has to decide to keep or replace the sow. So, there are 20 decision stages. To simplify the situation, we say that a sow can be kept for a maximum of 4 parities. Therefore, the states a sow can be in are parities 1, 2, 3 and 4.

The profits per decision (keep or replace the sow) can be calculated for all parities. After parity 4 (ie, in state 4) a sow will always be replaced by a replacement gilt (producing her first litter). The profit of replacing a sow is the slaughter value minus the purchase price plus the [gross returns - feed costs] of a sow in state 1.

What is the profit in the following year when a sow has been replaced after 3 parities? Answer in cell G94: [ ]

Press PgDn

The following table gives an overview of the profit of keeping and replacing (numbers in brackets are the states):

From/To	(1)	(2)	(3)	(4)
(1)	195	320		
(2)	205		400	
(3)	225			340
(4)	210			

To simplify again, there is no genetic improvement over time and also no discounting, so:

Extra returns from replacement sow in state i+1, compared with state i due to genetic improvement (US$): 0

What is the profit from a decision in the long term? Press PgDn to see what steps should be taken to answer this question.

We first have to decide what the value of the sows is at the end of our planning horizon (stage 20). The best estimation we have till now is the slaughter value:

Stage 20

State	Value
4	195
3	210
2	190
1	180

Now we go back to decision stage 19: what is optimal, to keep or to replace the sow? The profit of, for instance, keeping a sow in parity 2 (= state 2) is the profit from the sow in the following parity and the profit from the optimal decision taken at stage 20 for a sow in parity 3 (= state 3). The model calculates this as: cell E108 + cell C130.

Press PgDn

Which cells do we have to sum to get the profit from replacing a sow in parity 2 (state 2) in stage 19? Choose one of the following options:

A. Only cell C108
B. Cell E108 + cell C131
C. Cell C108 + cell C132

Answer in D148:

Compare the profits from keeping and replacing a sow in parity 2 (state 2) at stage 19. What should the farmer decide? K(eep) or R(eplace)?

Answer in D153:

The following tables show the profits from replacing and keeping at stage 19 and stages 4 to 1 and the optimal solution for the different stages. Stages 18 to 5 are also calculated, but hidden: they have been calculated in the same way as the stages shown.

Press PgDn

K indicates keeping to be optimal, R indicates replacing, K/R indicates keeping and replacing to be indifferent.

Stage 19:

State	Replace	Keep	Max	K/R?
4	390		390	R
3	405	535	535	K
2	385	610	610	K
1	375	510	510	K

Is the following statement T(rue) or F(alse)? (answer in I175)

The output of stage k is the input for stage k-1.

Press PgDn

Stage 4:

State	Replace	Keep	Max	K/R?
4	5275		5275	R
3	5290	5290	5290	K/R
2	5270	5365	5365	K
1	5260	5360	5360	K

Stage 3:

State	Replace	Keep	Max	K/R?
4	5570		5570	R
3	5585	5615	5615	K
2	5565	5690	5690	K
1	5555	5685	5685	K

Press PgDn

Stage 2:

State	Replace	Keep	Max	K/R?
4	5895		5895	R
3	5910	5910	5910	K/R
2	5890	6015	6015	K
1	5880	6010	6010	K

Stage 1:

State	Replace	Keep	Max	K/R?
4	6220		6220	R
3	6235	6235	6235	K/R
2	6215	6310	6310	K
1	6205	6335	6335	K

We assume that at the beginning of the planning horizon (stage 1) all the animals are in state 1. What is the optimal decision in stages 1 to 4? (Keep the sow when 'keep' and 'replace' are equal). Compare your answer with the figure on the following page.

Press PgDn

The Optimal Path is:

State				
4				R
3			K	
2		K		
1	K			
Stage	1	2	3	4

RETENTION PAY-OFF (optional, 5 min, skip it by pressing PgDn twice)

The outcome of the model can be used to estimate the Retention Pay-Off (RPO). The RPO is the total extra profit from keeping a sow compared with immediate replacement.

Press PgDn

Use the values of stage 1 to calculate the RPO for sows in parity 1, in parity 2 and in parity 3. (Because all animals are replaced after 4 parities, we cannot calculate an RPO for sows in parity 4.)

Enter your answers in the following table:

Parity	1	2	3
RPO:			

Press PgDn for some sensitivity analyses with the DP-model.

SENSITIVITY ANALYSES (optional, 10 min)

The farmer does not believe that the previous calculations are suitable for his/her situation. The purchase price of a sow may be US$225 on average, but (s)he has got the barn and labour available to rear sows himself/herself. The rearing costs therefore will not exceed US$175 per sow.
What is the optimal path in this specific situation? In which parity does the farmer have to replace the animals? 1, 2, 3 or 4?

Enter your answer in cell F272: [ ]

Press PgDn

In reality a replacement sow may be a little better than the older sows, because of genetic improvement. Assume that every replacement sow will yield net returns that are US$8 higher than the net returns from a replacement sow in a previous stage.

What is the optimal replacement policy for this farmer (including the lower purchase price)? Parity 1, 2, 3 or 4? (Change cell H116)

Enter your answer in cell F290: [ ]

Press PgDn

	A	B	C	D	E	F	G	H	I	J
301	==									
302										
303	You have finished the current exercise.									
304	You can now choose to:									
305	- return to the introductory file by opening the file 'INTROAHE.WK1'									
306	- quit the computer exercises by closing the spreadsheet									
307										
308	==									
309		COMPUTER EXERCISES ON ANIMAL HEALTH ECONOMICS								
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313	Design:		C.W. Rougoor & A.W. Jalvingh							
314	Supervisors:		A.A. Dijkhuizen, R.S. Morris & R.B.M. Huirne							
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317		Department of Farm Management								
318		Hollandseweg 1								
319		NL-6706 KN Wageningen								
320										

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=====================================================================
            COMPUTER EXERCISES ON ANIMAL HEALTH ECONOMICS
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                   Version 2.0 - September 1995
=====================================================================
Current exercise: MARKOV.WK1     Markov Chain Simulation
Title of case:    (A) Pneumonia in sheep
                  (B) Mastitis in dairy cattle
=====================================================================
Purpose:  1. (ad A) Understanding the principles of a Markov chain.
          2. (ad B) Comparing different strategies for treating mastitis
             to find the economically best one.
Keywords: Dynamic, transition matrix, state, vector, stable situation.
Time:     (A) will take about 15 min. The first part of (B) takes
          15 min. The second part (optional; dynamic transition rates)
          takes another 15 min.
=====================================================================



                                                          Press PgDn

                 MARKOV CHAIN SIMULATION: PNEUMONIA IN SHEEP

In a flock of 90 sheep, 18 are suffering from pneumonia, the other 72
are healthy. Once animals are infected, they stay infected for the
rest of the year. After one year, 9 of the sick animals have recovered,
but 18 of the 72 healthy animals have become infected.

What is the probability of a healthy animal being infected next
year? (Answer in E30):                   [        ]
What is the probability of an infected animal being healthy next
year? (Answer in E32):                   [        ]

These 2 probabilities are put in the TRANSITION MATRIX. Complete the
matrix:
          FROM/TO | Uninf.   Inf.
                  |
          ________|___________________
          Uninf.  |
          Inf.    |
                                                          Press PgDn

Multiplying this matrix by a vector with the situation in year 0,
results in the situation in year 1:

situation year 0   x   transition matrix    =     situation year 1

|    72       18 |   x   |   0.75     0.25 |   =   |     63       27 |
                         |    0.5      0.5 |

Summarized for years 0 to 4:

           Year    Uninf.    Inf.
              0        72      18
              1        63      27
              2        61      29
              3        60      30
              4        60      30

                                                          Press PgDn
```

As you can see, after a couple of years, the number of uninfected animals does not change any more; a steady state has been reached.

Determine the steady state when at the start 75 animals are infected. Change the value in cell B47.

Enter your answers in F70 and F71:

Number of infected animals:	
Number of uninfected animals:	

More about the steady state on the next page.

Press PgDn

The steady state seems to be independent of the initial situation. Now we have found a steady state after some multiplications. It is also possible to calculate the steady state at once by solving the following equations:

0.75 x (% Uninf.) + 0.5 x (% Inf.) = % Uninf.
0.25 x (% Uninf.) + 0.5 x (% Inf.) = % Inf.
% Uninf. + % Inf. = 100%

Solving this problem results in: 33.33 % Infected
66.67 % Uninfected

The two states in this model are called recurrent. Another possibility is that one of the states is absorbing: let us assume that an animal that has been infected once, will never be free of the disease again.

Go to the next page to complete the transition matrix for this situation.

Press PgDn

Enter the correct values in the transition matrix:

FROM/TO	Uninf.	Inf.
Uninf.		
Inf.		

In this case 'infected' is an absorbing state: once an animal has reached this state, it will never leave it again.
The state 'uninfected' is now a transient state: a sheep that passes this state, will never come back to it again. In this situation all sheep will be infected eventually, independent of the initial situation. So the steady state will be: 0 uninfected and 90 infected.
Now we extend the model with an extra state: immune.

Press PgDn

The transition matrix is given:

FROM/TO	Uninf.	Inf.	Immune
Uninf.	0.5	0.25	0.25
Inf.	0	1	0
Immune	0	0	1

Are the different states absorbing (A), transient (T) or recurrent (R)?

(NB: drawing a transition diagram might be useful and illustrative).

	A, T, R?
Uninf.:	
Inf. :	
Immune:	

How many animals (from a total of 90) will eventually be infected when at the start all sheep are uninfected? (cell H137):

Press PgDn

Is this steady state independent of the initial situation? Y(es) or N(o)? (answer in E142):

The next case is an example of a matrix with only recurrent states:

MARKOV CHAIN EXAMPLE: MASTITIS

A dairy farmer has some problems with the animals: a lot of them suffer from mastitis, so (s)he asks you for advice. At the moment the herd consists of the following animals:

Initial herd:	Uninfected	240
	Strep. agalactia	15
	Strep. spp.	15
	Staphylococcus	22
	Other infections	8
	TOTAL	300

Press PgDn

A Markov Chain transition matrix is given. Each cell represents the annual probability of transition from different states on the left-hand side of the matrix to states appearing over the matrix.

FROM/TO	Uninf.	Strep. ag.	Strep. spp.	Staph.	Other Inf.	Culled	SUM
Uninfec.	0.52	0.03	0.02	0.12	0.02	0.29	1.00
Strept ag.	0.70	0.01	0	0	0	0.29	1.00
Strept spp.	0.70	0	0.01	0	0	0.29	1.00
Staph.	0.10	0	0	0.40	0	0.50	1.00
Other infec.	0.71	0	0	0	0	0.29	1.00
Culled	1.00	0	0	0	0	0	1.00

Calculate the number of Staphylococcus infections in year 1.
Enter your answer in cell G177:

The transition matrix is used to calculate the situation on the farm over a couple of years. The results are given in the STATE MATRIX:

Time	Uninfec.	Strep. ag.	Strep. spp.	Staph.	Other infect.	Culled	TOTAL
0	240	15	15	22	8	0	300
1	154	7	5	38	5	92	300
2	187	5	3	33	3	68	300
3	177	6	4	36	4	74	300
4	179	5	4	36	4	73	300
5	178	5	4	36	4	73	300
6	178	5	4	36	4	73	300
7	178	5	4	36	4	73	300

As you can see, quite a lot of animals suffer from Staphylococcus. After a couple of years a steady state is reached.

Press PgDn

There are different options of changing the present situation:

1. Using antibiotics for dry-period treatment of the animals. 25% of the animals with Staphylococcus will be clean the next year, instead of 10%. 25% instead of 40% remain infected with Staphylococcus.
2. Bringing the number of new Staphylococcus infections down by some extra care for hygiene. Instead of 12% new infections, 4% of the clean cows will suffer from Staphylococcus the next year.

Create the transition matrix for the first strategy. You can do this by changing the values in the original transition matrix. Check the last column in the matrix: the summation of all probability rates must equal 1!

The STATE MATRIX gives you the new situation. Make sure you write down the steady state situation, because you need it later. Make the probabilities equal again to the default values and recalculate strategy 2.

Press PgDn

The losses due to mastitis are:

Streptococcus ag.	260	(US$ per infected cow per year)
Streptococcus spp.	260	
Staphylococcus	300	
Other infections	210	
Cost of Culling	340	(US$ per culled cow)

The costs of the different strategies are:

Strategy 1 (US$ per year)	1900
Strategy 2 (US$ per year)	2500

These values can be used to calculate the costs for the different strategies. You can fill in the number of animals suffering from the different bacteria (in the steady state) in the scheme on the next page. You also have to fill in the number of animals culled.

Press PgDn

	A	B	C	D	E	F	G	H	I

Number of animals suffering from:

Strategy:	Str ag.	Str spp.	Staph.	Other	Culled	Costs Strat.	Total Costs
No treatment						0	0
Strategy 1						1900	1900
Strategy 2						2500	2500

The model multiplies these values by the costs as defined previously, and calculates the total costs.

What would you advise the farmer?

Best strategy (Fill in No or 1 or 2 in cell H255): [ ]

DYNAMIC TRANSITION RATES (optional, 15 min)

Now we assume that the number of animals infected with Streptococcus agalactia depends on the number of animals uninfected or infected with Streptococcus agalactia during the previous year. The probability of an uninfected animal becoming a new Streptococcus agalactia case was calculated as the probability of an uninfected animal not avoiding effective contact with all cases present in that year.

In this situation a fixed (static) transition matrix is insufficient. A second transition matrix is constructed.

Have a look at this matrix on the next page.

Press PgDn

TRANSITION MATRIX:

FROM/TO	Uninf.	Strep. ag.	Strep. spp.	Staph.	Other Inf.	Culled	SUM
Uninfec.	X	Y	0.02	0.12	0.02	0.29	1.00
Strept. ag.	0.70	0.01	0	0	0	0.29	1.00
Strept. spp.	0.70	0	0.01	0	0	0.29	1.00
Staph.	0.10	0	0	0.40	0	0.50	1.00
Other inf.	0.71	0	0	0	0	0.29	1.00
Culled	1.00	0	0	0	0	0	1.00

X = 1 - summation (D285 to H285)
Y = 1 - 0.995 to the power of(no. of strep. ag. in previous year)

These values can change over time, making the transition probabilities dynamic. In the state matrix the values are given per year.

We first need to define the initial herd. Press PgDn

```
Initial herd:       Uninfected            240
                    Strept. ag.            15
                    Strept. spp.           15
                    Staphylococcus         22
                    Other infections        8
```

Calculate X and Y for year 1 (give your answer in two decimal places in D310 and D311):

X =

Y =

Consider the following statement:

Y is always higher in a herd with a high percentage of animals suffering from Streptococcus agalactia than in a herd with a smaller percentage suffering from Streptococcus agalactia.

T(rue) or F(alse) (in F319)?

In the STATE MATRIX the situation is given over some years. X and Y are calculated and given for every year first:

Time	X	Y	Uninf.	Strept. ag.	Strept. spp.	Staph.	Other inf.	Culled
0	**	**	240	15	15	22	8	0
1	0.48	0.07	143.50	17.53	4.95	37.60	4.80	91.62
2	0.47	0.08	181.38	12.25	2.92	32.26	2.87	68.33
3	0.49	0.06	173.16	10.92	3.66	34.67	3.63	73.96
4	0.50	0.05	176.22	9.34	3.50	34.65	3.46	72.83
5	0.50	0.05	176.61	8.15	3.56	35.01	3.52	73.15
6	0.51	0.04	177.42	7.15	3.57	35.19	3.53	73.14
7	0.51	0.04	178.00	6.32	3.58	35.37	3.55	73.18

Press PgDn

Assume that not 15 but 65 animals are infected with Strept. ag. in the initial situation. Will Y be higher or lower in year 1 than in the previous situation?

Enter your answer in cell H346; H(igher) or L(ower):

What do you think will happen over a 7-year period: will Y remain completely different from the Y in the previous situation or not? Check your answer by filling in the new situation in the defined initial situation (cells E302 to E306). (The herd size has not changed, so you have to bring the number of uninfected animals down.)

Press PgDn

```
      A         B         C         D         E         F         G         H       I
361 ======================================================================
362
363 You have finished the current exercise.
364 You can now choose to:
365 - return to the introductory file by opening the file 'INTROAHE.WK1'
366 - quit the computer exercises by closing the spreadsheet
367
368 ======================================================================
369         COMPUTER EXERCISES ON ANIMAL HEALTH ECONOMICS
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374 Supervisors:      A.A. Dijkhuizen, R.S. Morris & R.B.M. Huirne
375 (c) Copyright:
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377         Department of Farm Management
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379         NL-6706 KN Wageningen
380
```

A	B	C	D	E	F	G	H	I

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COMPUTER EXERCISES ON ANIMAL HEALTH ECONOMICS
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==

Current exercise: MONTCAR.WK1 Monte Carlo Simulation
Title of case: Aujeszky's disease in swine

==

Purpose: 1. Understanding Monte Carlo simulation.
2. Simulating the number of animals infected with Aujeszky's disease in a herd and its financial effect over time.

Keywords: Dynamic, random sampling, simulation.

Time: Approximately 30 min for the main exercise. Another 10 min for the optional exercise (different initial situation).

==

Press PgDn

MONTE CARLO SIMULATION: AUJESZKY'S DISEASE

Assume the following transition matrix with 3 possible states an animal can be in:

From/to	A	B	C	SUM
A	0.60	0.38	0.02	1
B	0.05	0.85	0.10	1
C	0.03	0.87	0.10	1

where: A = hogs are healthy
B = hogs are infected with Aujeszky
C = hogs infected with Aujeszky and secondary infections

Number of hogs of a farmer: 40

Press PgDn

A Markov chain demands an initial herd. Assume that in period 0 all animals are healthy.
A Markov chain calculates the situation in the next period as:

	A	B	C
Period 1	24.00	15.20	0.80
Period 2	15.18	22.74	2.08

A Markov chain can also be used to calculate a stationary situation.
In this case:

	A	B	C
Stationary:	4.28	32.06	3.66

Monte Carlo simulation determines the situation in the next period by random sampling for each hog. Let us simulate the situation in period 1.

Press PgDn

```
    |    A    |    B    |    C    |    D    |    E    |    F    |    G    |    H    |  I
 61
 62  The model will draw a random number between 0 and 1. When the number
 63  is lower than or equal to 0.60, the hog will be in state A. When the
 64  number is higher than 0.60 but lower than or equal to 0.98, the hog
 65  will be in state B, etc. This corresponds with the first row of the
 66  transition matrix. Cell B71 shows the number drawn, cell C71 the
 67  corresponding state.
 68
 69           Random   State
 70
 71             0.4382  A
 72
 73  The farmer has 40 hogs, so we have to make 40 iterations:
 74
 75  Number of iterations:          40
 76
 77  Now you can press <CTRL> S (Excel-user) or <ALT> S (Lotus- and Quat-
 78  tro Pro-user) to start the simulation. Lotus and Excel-user: look at
 79  cells B71 and C71: you will see the changing of number and text
 80  depending on the state the hog is in.                      Press PgDn
 81
 82  Quattro Pro does not update these cells after each iteration. The
 83  outcome appears in the following table. To see the effect of the
 84  random sampling, we can do more replicates.
 85  Press <CTRL> or <ALT> S again: cell C88 will change to 2; the second
 86  replicate. Go on till the table is completely filled.
 87
 88  Replicate number       0
 89                                REPLICATE
 90     State        1        2        3        4        5   Avg %   SD of %
 91
 92         A        0        0        0        0        0    0.00      0.00
 93         B        0        0        0        0        0    0.00      0.00
 94         C        0        0        0        0        0    0.00      0.00
 95
 96  To get a clear view of the differences between the replicates, you
 97  can have a look at a graph with the 5 replicates. Press <CTRL> G
 98  (Excel), <ALT> G (Lotus) or <ALT> Q (Quattro Pro). The 5 replicates
 99  may differ considerably. Pressing any key will bring you back to
100  this screen.                                               Press PgDn
101
102  What if there are 250 hogs instead of 40?
103
104  Let us repeat the simulation with 250 hogs: change cell D75 to 250.
105  Press <CTRL> R (Excel-user) or <ALT> R (Lotus- and Quattro Pro-user).
106
107  Replicate number       0
108
109                                REPLICATE
110     State        1        2        3        4        5   Avg %   SD of %
111
112         A        0        0        0        0        0    0.00      0.00
113         B        0        0        0        0        0    0.00      0.00
114         C        0        0        0        0        0    0.00      0.00
115
116  The model calculates the average percentage of animals in the different
117  states and also the standard deviation of this percentage (last columns
118  of the tables; these values are only meaningful when all replicates are
119  done). Compare the standard deviations for 40 and 250 iterations.
120                                                             Press PgDn
```

Let us return to the farmer with only 40 hogs. Till now, we have only looked at period 1. We also want to know what happens over time, for instance 7 periods. Let us start with an average situation. The situation in period 0 is sampled from the stationary situation calculated with the Markov Chain (cells C55 to E55):

	Situation hog
Period 0:	B
Period 1:	B
Period 2:	C
Period 3:	B
Period 4:	C
Period 5:	B
Period 6:	B

Change cell D75 again to 40 iterations. Press <CTRL> P (Excel) or <ALT> P (Lotus and Quattro Pro) to simulate the 7 periods.

The results of this simulation appear on the next page.

Press PgDn

Replicate number 0

	Period						
State	0	1	2	3	4	5	6
A	0	0	0	0	0	0	0
B	0	0	0	0	0	0	0
C	0	0	0	0	0	0	0

The model has simulated the situation over 7 periods for each hog. The situation in period i depends on the situation in period i-1. We use the probabilities from the transition matrix defined at the beginning of this exercise. Therefore, when in period 2 a hog is in state B, the probabilities belonging to state B will be used in period 3.
(Remember: this is different from the previous situation: there we did 5 independent simulations for 1 period, here we only do 1 simulation, but for 7 different periods).

Press PgDn

Have a look at the graph that shows the distribution over time of your last simulation: Press <CTRL> F (Excel) , <ALT> F (Lotus) or <ALT> W (Quattro Pro).

What would the situation over time be if we had used a Markov Chain instead of a Monte Carlo simulation and the stationary situation was the initial situation? A, B or C?

A. Exactly the same situation in period 0 as with Monte Carlo, but a smooth line to the situation in period 6.
B. The graph would show 3 horizontal, stable lines.
C. The situation over time would be exactly the same as with Monte Carlo.

Answer in cell D175: [ ] Press <F9> after you have given the answer.

Press PgDn

	A	B	C	D	E	F	G	H	I

182 FINANCIAL LOSS

184 Let us assume that the financial loss from Aujeszky's disease can be
185 quite high, especially when owing to the disease, other infections occur.
186 Assume that the costs of the disease are:

		US$ per hog per period
190	Aujeszky only:	20
191	Aujeszky and sec. inf.:	150

193 Calculate the costs of the disease in period 6 for this farmer.
194 Answer in cell D194: [ ] US$. Press <F9> after you have
195 given the answer.

198 Repeat the simulation 4 times by changing the replicate number to
199 zero (cell C142), press <ENTER> and <F9>. The table is cleared now.
200 Press PgDn

202 You can press <CTRL> or <ALT> P again for a replicate.
203 For every replicate you can look at the graph by pressing <CTRL> F
204 (Excel), <ALT> F (Lotus) or <ALT> W (Quattro Pro).

206 Calculate the costs of the disease for all replicates and compare
207 the costs.

209 OPTIONAL EXERCISE (10 min)

211 In the calculations over time, the situation in period 0 was sampled
212 from the stationary situation. Assume that the farmer is sure that
213 the farm is totally free of the disease at the moment. All animals
214 are then in state A.

216 Simulate the situation for periods 1 to 6. You can do this by
217 changing cell C130 in 'A' (all animals are in state A in period 0).

219 Press PgDn

222 Have a look at the graph by pressing <CTRL> F (Excel), <ALT> F (Lotus),
223 or <ALT> W (Quattro Pro).
224 What graph do you expect when the number of animals is much higher?

226 You can see the effect of an increasing number of animals as follows:

228 Change after a simulation the replicate number to zero but do not
229 press <F9>. The table is not cleared. Press <CTRL> or <ALT> P: the
230 simulation will be repeated and the number of animals in the 3 states
231 are the total number of 2 simulations. Have a look at the graph.
232 You can repeat this as often as you like: at the end you get a very
233 smooth graph.

238 Press PgDn

```
   |    A    |    B    |    C    |    D    |    E    |    F    |    G    |    H    |  I  |
241|=====================================================================
242|
243|You have finished the current exercise.
244|You can now choose to:
245|- return to the introductory file by opening the file 'INTROAHE.WK1'
246|- quit the computer exercises by closing the spreadsheet
247|
248|=====================================================================
249|        COMPUTER EXERCISES ON ANIMAL HEALTH ECONOMICS
250|               = Principles and Applications =
251|                 Version 2.0 - September 1995
252|=====================================================================
253|Design:           C.W. Rougoor & A.W. Jalvingh
254|Supervisors:      A.A. Dijkhuizen, R.S. Morris & R.B.M. Huirne
255|(c) Copyright:
256|        Wageningen Agricultural University
257|        Department of Farm Management
258|        Hollandseweg 1
259|        NL-6706 KN Wageningen
260|
```

```
| A | B | C | D | E | F | G |
======================================================================
            COMPUTER EXERCISES ON ANIMAL HEALTH ECONOMICS
                   = Principles and Applications =
                    Version 2.0 - September 1995
======================================================================
Current exercise: DECANAL.WK1     Decision Analysis
Title of case:    Left-displaced abomasum in cattle
======================================================================
Purpose:   Comparing different strategies to treat displaced
           abomasum, taking risk into account.
Keywords:  Static, expected monetary value, maximin, minimax, maximax,
           utility, Bayes' theorem, value of information.
Time:      Total time necessary 60 min, including 15 min for utility,
           and 20 min for value of information. Both are optional.
======================================================================




                                                       Press PgDn

           DECISION ANALYSIS: DISPLACED ABOMASUM CASE

Left-displaced abomasum can be treated effectively by several
surgical techniques. In this example we want to compare 'normal'
surgery (such as left-flank abomasopexy, strategy a1) with 'closed'
surgical techniques (such as the bar suture technique, strategy a2).
A third possibility is not treating the cow but taking her to the
slaughterhouse (strategy a3) immediately.

These 3 strategies entail different costs and returns. When the
cow is treated, she might not recover. For both treatments this
probability is 20%. In that situation the cow has to be removed
immediately. Meat of animals treated with antibiotics is expected
to be condemned in 10% of the cases after surgery a1 and in 80%
of the cases after surgery a2, losing the slaughter value of
the animal.

                                                       Press PgDn


The different values are:
Slaughter Value (SV):                   800  (US$)
Cost of Culling (COC):                  400  (US$)
Surgery Costs a1 (SCa1):                215  (US$)
Surgery Costs a2 (SCa2):                100  (US$)

The cost of culling is the amount of money you save, by keeping the cow
instead of replacing her.

Payoff of the different strategies can be calculated as:
No surgery: SV
Surgery:
   Success: SV + COC - SCa(i)
   Failure: proportion not condemned x SV- SCa(i)



                                                       Press PgDn

```

The following table shows the payoff of the different strategies:

States	P(state)	Strategy a1	Strategy a2	Strategy a3
Success	0.8	985	1100	800
Failure	0.2	505	60	800

One criterion most often used to verify which strategy is the best, is the Expected Monetary Value (EMV). The EMV is the weighed average of the payoffs. Calculate the EMV for all the strategies.

What is the optimal strategy according to the EMV? a1, a2 or a3?

Answer in cell D76:

Press PgDn

The EMV is summarized in the following table:

	Strategy a1	Strategy a2	Strategy a3
EMV	889	892	800

The outcomes of the 2 surgery strategies are uncertain. The EMV implicitly assumes decision makers to be risk neutral. This means that the EMV does not differentiate, for instance, between US$100 for sure, and US$200 or 0 with a 50/50% probability. There are different criteria available that do take risk attitude into account.

The maximin criterion arises from a very pessimistic risk attitude. Each action is judged on its worst payoff. What is the optimal strategy according to this criterion? (Cell G97)

Press PgDn

The minimax regret criterion compares the amount by which the payoff could have been increased had the decision maker known what the result of surgery would be. What is the optimal strategy according to this criterion? Answer in cell F105:

A third criterion is a totally optimistic one: The maximax criterion simply amounts to scanning the payoff matrix to find its largest value. This criterion totally ignores all other payoffs. It is very much the approach of the desperate gambler. What is in our example the optimal strategy according to the maximax criterion? a1, a2 or a3? Answer in F114:

The difference in outcome of these 3 criteria arises from a different risk attitude. A very important thing these criteria do not take into account is any difference in probability of the outcome.

Press PgDn

	A	B	C	D	E	F	G

121 UTILITY (optional, 15 min, skip it by pressing PgDn 4 times)

123 A method that includes both probability of the outcome and risk
124 attitude is the expected utility model. The choice criterion is
125 maximization of the utility. The utility integrates information about
126 a decision maker's preference and subjective expectation in order
127 to identify preferred choices under uncertainty. The most direct way
128 to measure preferences is to estimate a decision maker's utility
129 function. This function relates the possible outcomes of a choice
130 to a single-valued index of desirability.

132 Assume in a lottery the chance of winning US$20000 or winning
133 nothing is 50/50. If the decision maker preferred a payment of
134 US$7000 for sure then:
135 A. The decision maker is foolish.
136 B. The decision maker is risk averse.
137 C. The decision maker is risk taking.

139 Answer in C139: [ ]

142 A utility function makes it possible to convert the money values for
143 each of the alternatives into utility values.
144 Suppose that a farmer's utility function for gains and losses is
145 adequately represented by:
146 Utility function: U(x) = x - (x^2)/4000

148 Calculate the utility of US$100, 500 and 900 for this farmer. Enter
149 your answer in the following table:

	100	500	900
Utility			

155 Does this farmer prefer US$500 for sure (a) or does (s)he prefer the
156 uncertainty of 50%/50% probability of US$100 / US$900 (b)? Use
157 the values calculated above and answer with a or b in cell A158.
158 [ ]

160 Press PgDn

162 Is this farmer risk averse (a) or risk taking (t)?
163 Answer in cell D163: [ ]

165 Read the following statements.
166 Which answer is correct: A or B (or C or D)?

168 1. A risk-neutral decision maker:
169 A. Cannot have a utility function.
170 B. Will come to the same conclusion by utility as by EMV.
171 Answer in cell D171: [ ]

173 2. Utility:
174 A. Reflects the attitude of the decision maker.
175 B. Is a number.
176 C. Is useful to give meaning to extreme monetary values.
177 D. All of the above answers are correct.
178 Answer in cell D178: [ ]

180 Press PgDn

The utility function is used to calculate the utility for the 3 strategies in the abomasum case:

S(i)	U(a1|Si)	U(a2|Si)	U(a3|Si)
		Utility	
Success	742.44	797.50	640.00
Failure	441.24	59.10	640.00
Exp. U	682.20	649.82	640.00

Which strategy is the best option for this farmer? a1, a2 or a3?
Answer in cell D194:

So far the use of utility; let us return to the monetary value:

Press PgDn

EXTRA OPTION: VALUE OF INFORMATION (optional, 20 min)

The farmer asks the veterinarian to predict the result of surgery. The veterinarian warns the farmer that the predictions are not always correct, but correct or not, the farmer has yet to pay for it.

Price prediction: 15 (US$)

The next table shows the total profit with the price of a prediction included:

States	P(state)	a1	a2	a3
			Strategy	
Success	0.8	970	1085	785
Failure	0.2	490	45	785
EMV		874	877	785

Press PgDn

The prediction can be z(1), which means that most probably surgery will be successful, or z(2), which indicates failure of surgery. On the next page you will find a table with the likelihoods of the various signals of the prediction (z(1) and z(2)) relative to the possible states (success or failure).

These values are used to calculate the joint probability, this is the probability of both being in a certain state and getting a certain prediction: P(z(i) and Si). This value is necessary to calculate the posterior probability: the chance of a specific state, given a specific prediction.

Press PgDn to have a look at this table.

States	P(state)	P{z(k)|state(i)} z(1)	z(2)		Joint Probabilities z(1)	z(2)
Success	0.8	0.8	0.2		0.64	0.16
Failure	0.2	0.4	0.6		0.08	0.12
				P{z(k)}	0.72	0.28

States	Post. Probabilities P(Si|z1)	P(Si|z2)
Success	0.89	0.57
Failure	0.11	0.43

What is the probability of success when the veterinarian predicts that surgery will fail (z(2))? (Cell G257):

With these posterior probabilities and the monetary payoffs, we can calculate the monetary value of each action, just by multiplying the payoffs by the posterior probabilities and summing them.

What is the monetary value of a1 when the result of the prediction is z(1)?
Answer in cell D268:

The table on the next page lists the EMVs of the different strategies for the different predictions (NB: due to the posterior probabilities being rounded off, your hand-calculation might be slightly different from these values).

Press PgDn

		z(1)	z(2)
E[a(j)|z(k)]:	a1	916.67	764.29
	a2	969.44	639.29
	a3	785.00	785.00
	Optimal strategy:	a2	a3

What is the expected monetary value of the strategy of asking for a prediction? To answer this question you have to take the probability of the different predictions into account (you can find them in cells F248 and G248), and multiply them by the EMVs of the optimal strategy. So: EMV of Bayes' strategy = 917.80

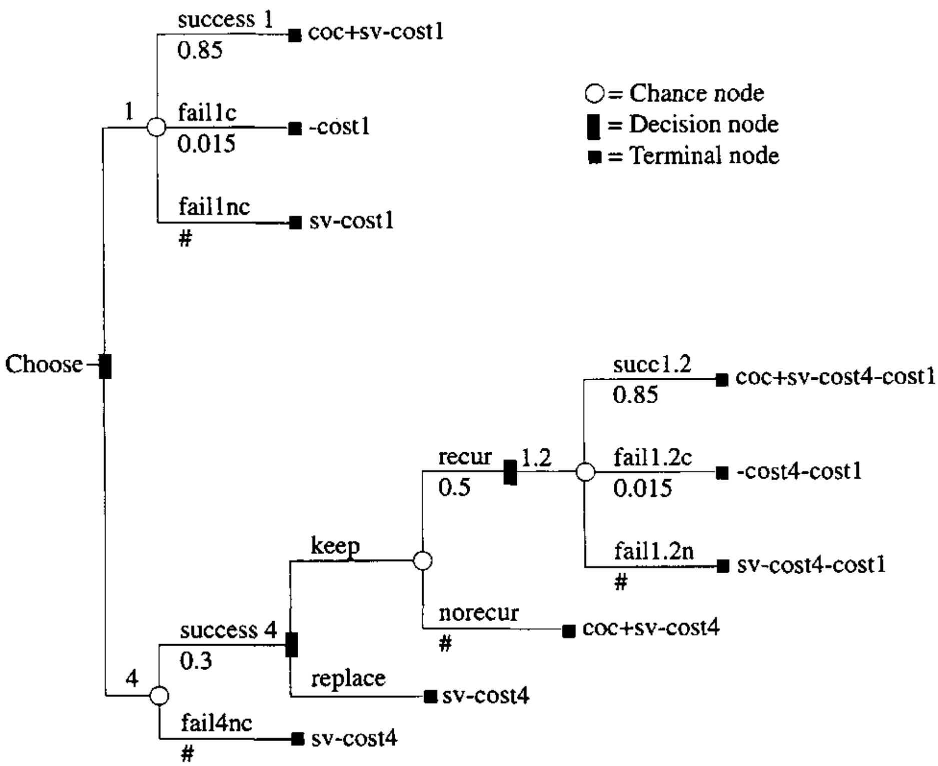
This value has to be compared with the value of the optimal decision without a prediction (cells C87 to E87). Was the prediction worth its money? Y(es) or N(o)? Answer in cell F297:

Press PgDn

```
   |    A    |    B    |    C    |    D    |    E    |    F    |    G
301|
302|The veterinarian has got the idea that the predictions are very
303|useful: (s)he believes a farmer is willing to pay US$50.
304|Do you agree? Y(es) or N(o)? Cell F304:              [         ]
305|
306|
307|
308|Till now we have assumed that strategies a1 and a2 both have a proba-
309|bility of 0.2 of failure. In fact, the probability of failure is 0.25
310|for strategy a2 and 0.15 for strategy a1. Besides surgery or culling,
311|there is a fourth strategy not taken into account yet: rolling the
312|cow to effect physical abomasum replacement. This method has a high
313|rate of recurrence of the condition and a lower rate of recovery (0.30),
314|but it may be preferred because it is noninvasive and inexpensive.
315|Decision-tree analysis is a method that can deal with different
316|probabilities, and it gives a clear overview of the possibilities.
317|
318|There is an exercise available on decision-tree analysis. Instructions
319|can be found in the introductory file INTROAHE.WK1.
320|                                                       Press PgDn
321|=====================================================================
322|
323|You have finished the current exercise.
324|You can now choose to:
325|- return to the introductory file by opening the file 'INTROAHE.WK1'
326|- quit the computer exercises by closing the spreadsheet
327|
328|=====================================================================
329|          COMPUTER EXERCISES ON ANIMAL HEALTH ECONOMICS
330|                  = Principles and Applications =
331|                  Version 2.0 - September 1995
332|=====================================================================
333|Design:             C.W. Rougoor & A.W. Jalvingh
334|Supervisors:        A.A. Dijkhuizen, R.S. Morris & R.B.M. Huirne
335|(c) Copyright:
336|          Wageningen Agricultural University
337|          Department of Farm Management
338|          Hollandseweg 1
339|          NL-6706 KN Wageningen
340|
```

Decision-tree analysis: the program SMLTREE[1]

After you have started the program, you must load the tree from the file DECTREE, available on the directory where you have put the computer exercises on animal health economics. You can see a list of names of branches included in the model. Choose the branch CHOOSE (just by pressing Enter); this is the first branch of the tree. The program does not show the whole tree on the screen. Use '+', to bring you one level deeper into the tree. If you want to see the entire tree (5 levels) keep pressing '+'. This is what you will see eventually:



Two branches of the displaced abomasum tree have already been made for you: strategy a1 and strategy a4. CHOOSE is a decision node: this is shown by a closed rectangle (▮). The different strategies are chance nodes: represented by an open circle (O). Besides these, there are also terminal nodes (small closed squares, ▪), they form the last part of a tree.

The following names are used in this tree:

success1	=	strategy a1 is successful
fail1c	=	strategy a1 failed and the meat is condemned
fail1nc	=	strategy a1 failed but the meat is not condemned

[1] If you do not have the program SMLTREE available, you can draw the tree by hand and calculate the answers by hand. However, questions 5 to 8 cannot be answered without SMLTREE.

coc	= costs of culling
sv	= slaughter value
cost1	= the costs of strategy a1
1.2	= strategy a1 will be used as a second option

Let us have a look at the tree. We start with strategy a1 (move through the tree by using the backspace key, Ctrl PgUp, Ctrl PgDn, TAB, arrow keys and by typing numbers. If you move from left to right, typing 1 and pressing Enter will bring you to the first branch etc.): The probability of success is 0.85. The monetary value of this branch is the cost of culling (coc) + the slaughter value (sv) - costs of strategy a1 (cost1). SMLTREE has the possibility of entering the monetary value as a logical expression of variables. Before analysing the tree, the model will ask you to assign values to these variables. As you can see, we now distinguish between condemned and not-condemned meat. The probability of meat being condemned is 10%, the probability of failure is 15%. Therefore, the probability of failure and condemned meat is 0.10 x 0.15. A probability of # means that the program will calculate the probability for you (= 1 - other probabilities).

Strategy a4:
When strategy a4 is successful, the farmer can decide to keep the cow but can also decide to replace her when (s)he does not want to take the risk of recurrence of the displaced abomasum. When the cow is kept, there is a probability of 50% that the displacement in that particular cow will recur. We assume that the farmer chooses strategy a1 the second time the displacement occurs ((s)he has lost faith in strategy a4). The last part of the tree is the same as for strategy a1. The only difference is the monetary value: the costs of strategy a4 are also taken into account.

1. Analyse what the farmer should decide **after** (s)he has chosen strategy 4 and the 'rolling' being successful: keep or replace? You can do this by highlighting 'success4' with your cursor (you always have to be on a branch name to work with the model), type '/','Analyze', choose the option 'Foldback'. Give the values of coc, sv, cost4 and cost1 (in case you have forgotten: coc = 400, sv = 800, cost4 = 60, cost1 = 215).
2. Add strategies a2 and a3 to the tree. Put your cursor on 'choose', type '/', 'Edit tree', 'Add node', 'After current node', use the arrow keys to put the branch in the right place in between the other branches, press <INS>. Give a name to the branch (give every branch a unique name of maximum 8 characters). Define the node type. Be aware of the fact that the node type asked for is the node type following this branch ('1' is a chance node because after you have chosen 1, there is a chance of success and a chance of failure). There are different possibilities:

    D = decision node
    T = terminal node
    C = chance node

The other possible node types are more advanced and not necessary for this tree.

As stated in the spreadsheet model, the probability of failure is 0.25 for strategy a2. In case of failure, meat with antibiotics is expected to be condemned in 80% of the cases after strategy a2. Go on adding these branches till you have completed your tree. (If you have made a mistake, for example, have entered the wrong node type, just assign a value to the variables the program asks for. Then, when you are back in the menu, put the cursor on the appropriate term and edit the tree).

3. Determine the optimal decision by analysing the complete model (the way you analysed part of the model before).
   What is the Expected Monetary Value of strategies a1, a2, a3 and a4?

Sensitivity analysis (optional, 20 min)

Culling is not a very good alternative, as you may have noticed. We made this calculation for an average cow, however. There are also cows for which culling is, economically speaking, a better alternative than treating, because they perform below average.

4. What variable do we have to change to simulate cows that produce below average?
   If you do not have the program SMLTREE available, you cannot do these sensitivity analyses.

5. Find the threshold for this variable: type '/', 'analyze', 'threshold', compare strategy a1 (the best strategy on average) with culling (= strategy a3) (You can find this comparison with the arrow keys.) Enter the name of the variable (coc). Make the minimum and maximum of the variable 0 and 1000. What does the calculated threshold mean?
   Now the program asks for a variable for 2-way analysis. We want to see the influence of the price of strategy a1 on the threshold of the coc: what is, for instance, the threshold of the coc when the price of strategy a1 is US$300 instead of US$215? A 2-way analysis can answer this question! Thus:

6. Enter 'cost1', enter 0 500 10 for min, max and step. Press Enter (we do not want to do the 3-way analysis). Give a character for the graph, for example '#'. Type 'g' to view the graph. Can you explain what you see?
   'Rolling' (strategy a4) is not profitable because of the low rate of success. How great is the effect of the rate of success on the profitability? Sensitivity analysis can give an answer to this question. We first have to change the probability value to a variable:
7. Put the cursor on 'success4'. Then press '/', 'edit tree', and 'probability'. Now you can enter a name for this new variable (for instance: prob4), delete the existing value and save with 'Y'.

   Now we can perform a sensitivity analysis on this new variable:

8. First clear the old graph by pressing 'C'. Move the cursor back to 'choose', press '/',

'analyze', 'sensitivity analysis' and the name of the variable. Now you have to give a minimum and maximum value for the variable and the size of the step; press the Escape key to clear and then enter some reasonable values. Press Enter.
Scroll through the screen to see at what level of the variable 'rolling' you can find the most optimal decision. Press G to have a look at the graph.
Can you explain what you see?

19.5 Answers

Production function (filename: PRFUNCT1.WK1)

E94 Total veterinary costs = 20 visits x variable costs per visit + fixed costs per year = 20 x F71 + F72 = 20 x 120 + 1500 = **3900**.

E95 20 visits result in 20.10 - 18.00 = 2.1 extra piglets per sow. The return from 1 extra piglet is US$30. So the total returns from extra piglets are 2.1 x 30 x (100 sows) = **6300** (in cell formulation: F77 x F78 x (E51 - E47).

D110 The marginal costs are: ΔTVC / ΔY (where Y = piglets per farm). In this case: (C110 - C109) / (B110 - B109) = 600 / 30 = 20.

D111 Marginal costs = (C111 - C110) / (B111 - B110) = 600 / 50 = **12**.

F183 You have to check the graph or the table to find the point where the marginal returns are equal to the marginal costs. This is with 300 extra piglets. Check the table: 300 extra piglets correspond with **35** visits.

F196 Now the marginal returns are equal to the marginal costs with 280 extra piglets. This corresponds with **30** visits.

F212 'No visit' should be preferred when the marginal returns never exceed the average costs. So, the break-even point is the point where the marginal returns are, at one stage, equal to the average costs but never exceed them. The lowest value of the AVC is 11.43. So, when the MR (= net returns from 1 extra piglet) is **11.43** it will always be smaller than, or equal to, the average costs.

Production function (filename: PRFUNCT2.WK1)

D92 Marginal costs of I compared with 0 are 21 - 0 = **US$21** (E76 - D76).

F93 Marginal returns of III compared with II are 1652 - 1617 = **US$35** (G73 - F73).

G110 For treatment II the marginal returns are still higher than the marginal costs (US$151 and 0 respectively), but for treatment III the marginal returns are smaller than the marginal costs (US$35 and 199 respectively). So, treatment III is 'one step too far' and the treatment previous to this one (treatment II) is the best.

G132 The returns from wool are now for treatment 0 to III respectively (27% of US$774 =) 209, 220, 262 and 272. The returns from ewes and lambs remain the same. So the total returns are now: US$777, 871, 910 and 918.
This gives the following marginal costs and returns:

	0	I	II	III
Marginal costs	0	21	0	199
Marginal returns	0	94	39	8

Again, treatment III is 'one step too far', so treatment II is still the best option.

Partial budgeting (filename: PARTBUD.WK1)

F44 The costs of surgery are extra costs: **4**.

F46 Less milk is returns foregone: **3**.

F47 Less feed necessary is reduced costs: **2**.

F48 The heavier weights of calves are additional returns: **1**.

F49 The increase in culling rate is extra costs or returns foregone: **4** as well as **3** are correct.

E74 The returns from a calf are:
male calf : (43+3.5)kg x US$6 x 0.88 survival = US$245.52
female calf: (40+3.5)kg x US$4 x 0.88 survival = US$153.12
82% is male, so the average returns are 0.82 x 245.52 + 0.18 x 153.12 = US$**229**.

G112 The reduced costs are the costs no longer obtained because less feed is necessary: 70 kg of milk less saves 70 x 0.5 = 35 kg of concentrates x US$0.20 = US$**7.00.**

F135 20% of US$340 = US$**68**.

D152 No: the net return from a caesarean section is negative (US$-208.66).

G164 No: in this situation the net return = US$-92.82, so still negative.

F173 No: the additional returns are US$30.34, there are no reduced costs, no revenues foregone, but yet the costs of surgery being US$150. These costs are higher than the returns.

Cost-benefit analysis (filename: COSTBEN.WK1)

F66 Discount factor year 1 = 1 / (1+0.05) = **0.95**.

F67 Discount factor year 2 = 1 / (1+0.05)^2 = **0.91**.

N37 Discount factor year 1 = 1 / (1+0.09) = **0.92**.

N44 0.92 x US$725 = US$**667**.

N56 Discount factors are for years 1 to 4: (1 / 1.06 =) 0.94, (1 / (1.06)^2 =) 0.89, 0.84 and 0.79. The present value of US$200 every year is (0.94 + 0.89 + 0.84 + 0.79) x 200 = US$**692**.

N66 Discount factor x 25 = 23.11, so the discount factor is 0.9244. Now we have to solve: 0.9244 = 1 / (1+i)^2.
=> (1+i)^2 = 1 / (0.9244)
=> i = **4%**.

F97 NPV is the total benefit minus total cost = G91 - F91 = US$25.58 - US$15.99 = US$**9.59**.

C98 B/C-ratio is the total benefit divided by total cost =
D91 / C91 = US$52.18 / US$37.46 = **1.39.**

F103 The NPV of strategy A is higher than the NPV of strategy B (US$14.72 compared with US$9.59), so strategy **A** is the best.

F108 The B/C-ratio of strategy A is lower than the B/C-ratio of strategy B (1.39 and 1.60), so strategy **B** is the best.

F116 **F**alse: the NPV shows what your net result is from your total investment. The B/C-ratio shows what your returns are for every dollar you have invested. So, when you want to get as much money back for every dollar you invest, the B/C-ratio is the best criterion.

A122 The real interest rate that makes the benefits equal to the costs is called the internal rate of return! An estimation of this value is given in cell C99: **23.9%**.

F134 **B**: When the real interest rate increases, the present value of future costs or benefits decreases. Strategy A entails many costs in years 1 and 2 and the benefits appear at the end, so a high real interest rate is negative for this strategy and has a great effect on the NPV and the B/C-ratio. Strategy B has costs and benefits both at the end, so the real interest rate will not have a great influence on the NPV and the B/C-ratio.

Linear programming (filename: LINPROG.WK1)

C47 One cow (=X) requires **1.25** hours of labour. So a = **1.25**.

D48 One sheep (=Y) requires 1/5 ha of grass. So b = **0.20** (and the complete grass constraint is: $0.50 \times X + 0.20 \times Y \leq 30$ ha).

E47 The total amount of labour available is **40** hours. (So the complete labour constraint is: $1.25 \times X + 0.15 \times Y \leq 40$ hours)

F74 The area below both lines are solutions which are feasible for these constraints (because both lines give maximal solutions), so area **B**.

F84 No: The maximal number of cows in the feasible area is 32 (labour is the limiting factor for that), so a barn for only 40 cows does not influence the feasible area.

D110 **T**rue: The returns can increase until the graphical representation of the returns just touches the feasible area at an angular point.

E136+E137

Not all the points given in the table are feasible points. The feasible points are:
(X,Y) = (20,100); (X,Y) = (0,150) and (X,Y) = (32,0). The total returns of these points are:
for (X,Y) = (20,100): 20 x US$600 + 100 x US$100 = US$22 000
for (X,Y) = (0,150): 0 x US$600 + 150 x US$100 = US$15 000
for (X,Y) = (32,0): 32 x US$600 + 0 x US$100 = US$19 200
The point with the highest net returns is the optimal point, which is (20,100). So the optimal number of cows is 20 and the optimal number of sheep is **100**.

F174 The objective function is indifferent for (20,100) and (32,0) when one of the graphical representations of this function touches both points. So, the slope of the objective function should be the same as the slope of the labour constraint: $1.25 \times X + 0.15 \times Y = 40$. So: $Y = (-1.25 / 0.15) \times X + 40 / 0.15$. The slope is $-1.25 / 0.15 = -8.33$. So the correct answer is **D**.

D185 The objective function is: 600 x X + net returns(sheep) x Y = max. So Y = (-600 / net returns(sheep)) x X + max / net returns(sheep). The slope of the objective function has to be -8.33. So -600 / net returns(sheep) = -8.33. This results in: net returns(sheep) = US$**72**.

D194 Now the slope of the objective function should be the same as the slope of the grass constraint: $-0.50 / 0.20 = -2.5$. So -600 / net returns (sheep) = -2.5. This results in: net returns(sheep) = US$**240**. (Have a look at the 2 previous answers for a more detailed explanation.)

Dynamic programming (filename: DYNPROG.WK1)

A54 All sows are replaced after parity 4, so there is the same number of animals in each parity. The average gross returns minus feed costs on the farm is the average of the four parities: (US$240 + 320 + 400 + 340) / 4 = US$**325**.

C68 The profit on a sow in parity 1 is the gross returns minus feed costs for parity 1 (US$240) and the change in value of the sow. Before the sow is in parity 1, her value is the purchase value (US$225). At parity 1, her value is the slaughter value (US$180). So the change in value is US$-45.
The profit on the sow is US$240 - 45 = US$**195**.

E68 The profit on the sow is H47 + (H48 - G48) = US$400 + (210 - 190) = US$**420**.

F68 The profit on the sow is I47 + (I48 - H48) = US$340 + (195 - 210) = US$**325**.

G94 The profit from replacing a sow after 3 parities is the slaughter value of the sow (cell H48: US$210) minus the purchase price of a young sow (cell F57: US$225) plus the gross returns minus feed costs of a sow in parity 1 (cell F47: US$240). So: US$**225**.

D148 **C**: The profit from replacing a sow in parity 2 is calculated in cell C108. This has to be summed with the optimal decision taken at stage 20 for a sow in parity 1: cell C132.

D153 The profit from keeping is E108 + C130 = US$400 + 210 = US$610.
The profit from replacing is C108 + C122 = US$205 + 180 = US$385.
Conclusion: **Keeping** is more profitable than replacing.

I175 **True**: the values of stage 20 are used in stage 19.

C251 The RPO of a sow in parity 1 is the profit from keeping (cell E214: US$6335) minus the profit from replacing (cell D214: US$6205): US$**130**.

D251 The profit from keeping (cell E213: US$6310) minus the profit from replacing (cell D213: US$6215): US$**95**.

E 251 The profit from keeping (cell E212: US$6235) minus the profit from replacing (cell D213: US$6235): US$**0**.

F272 Change cell F57 (purchase price) to US$175 and check the figure that shows the optimal path. The optimal path does not change: parity **4** is still the optimal moment to replace the sow.

F290 Change cell H116 (genetic improvement) to US$8 and check the figure that shows the optimal path. Now parity **3** is the optimal moment to replace the sow.

Markov chain simulation (filename: MARKOV.WK1)

E30 In the first year there are 72 healthy sheep. In the second year 18 of these sheep will be sick, so the probability of a healthy animal being sick next year is 18 / 72 = **0.25**.

E32 In the first year there are 18 sick sheep. In the next year 9 of these sheep will be healthy, so the probability of an infected animal being uninfected next year is 9 / 18 = **0.50**.

C38 The sum of the row has to equal one, so 1 - 0.25 = **0.75**.

D39 The sum of the row has to equal one, so 1 - 0.50 = **0.50**.

F70+F71

Change cell B47 to 75 (A47 automatically changes to 15). Now you can see that in year 4 the number of uninfected animals is **60** again, and the number of infected animals is **30**.

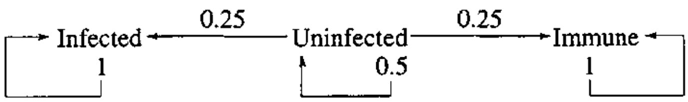
C107 **0.75**. This value has not changed

D107 **0.25**. This value has not changed

C108 **0**. Once animals are infected they will never become uninfected again.

D108 **1**. All animals that are infected once remain infected.

C132 Transient: once a sheep has passed this state it will never come back to this state again. The transition diagram belonging to this situation clarifies this:



C133 Absorbing: once an animal has reached this state, it will never leave it again.

C134 Absorbing: once an animal has reached this state, it will never leave it again.

H137 Eventually 50% of the animals will become infected and 50% of the animals will become uninfected, so **45** sheep will be uninfected. (Have a look at the transition diagram above).

E142 No: Compare for instance the situation where all animals are immune with the situation where all animals are infected.

G177 Number of staphylococcus infections in year 1 = 0.12 x uninfected + 0 x Strept. ag. + 0 x Strept. spp. + 0.40 x Staph. + 0 x other + 0 x culled = 0.12 x 240 + 0.40 x 22 = **37.6**.

A211 Strategy 1: You have to change cell C172 to 0.25 and cell F172 to 0.25. Have a look at the state matrix. The steady state is now:

Uninf. :	185
Strep. ag. :	6
Strep. spp.:	4
Staph.:	30
Other inf.:	4
Culled:	72

A218 Strategy 2: Change cells C172 and F172 back to 0.10 and 0.40 respectively. Cell F169 has to be 0.04 instead of 0.12. To make the sum of the row equal to 1.00 again, you also have to change the number of animals that remain uninfected: 0.60 instead of 0.52 (Cell C169). The steady state is now:

Uninf.:	203
Strep. ag. :	6
Strep. spp.:	4
Staph.:	14
Other inf.:	4
Culled:	70

C246 to G248

Fill in all the values the model calculated. After that the table will look like:

Strategy	Str. ag.	Str. spp	Staph.	Other.	Culled	Costs str.	Total
No	5	4	36	4	73	0	38 800
Strategy 1	6	4	30	4	72	1900	38 820
Strategy 2	6	4	14	4	70	2500	33 940

H255 **2**: This is the strategy that results in the lowest total costs (as you can see in the table above).

D310 You first have to calculate Y before you can calculate X. Y = 1 - 0.995^(15) = 0.07.
X = 1 - (0.07 + 0.02 + 0.12 + 0.02 + 0.29) = **0.48**

D311 Y = 1 - 0.995^(15) = **0.07**.

F319 **False**: Y = 1 - 0.995^(no. of ag. in previous year), so the number of animals with ag. is important, not the percentage! (A farm with 50 animals where 40% of the animals are suffering from Strep. ag. will have the same value for Y as a farm with 200 animals where 10% of the animals are suffering from Strep. ag. In both situations Y = 1-0.995^(20) = 0.095.)

H346 **Higher**: when more animals are infected, the risk of effective contact with a sick animal will be higher.
(When 65 animals are infected: Y = 1 - 0.995^(65) = 0.28.)

A352 Change cell E302 to 190 and cell E303 to 65 and have a look at the state matrix. Y starts high (0.28) but decreases over time. After 6 years Y is equal to the Y we calculated in the default situation.

Monte Carlo simulation (filename: MONTCAR.WK1)

A119 Most probably the standard deviations will be higher when only 40 replicates are made compared with 250 replicates.

D165 **B**: The initial situation is the stable situation, and one characteristic of a Markov chain is that when the stable situation is reached, the situation does not change any more.

D194 The costs in period 6 are (number of animals suffering from Aujeszky's disease) x US$20 + (number of animals suffering from Aujeszky's disease and a secondary infection) x US$150 = (cell H148) x 20 + (cell H149) x 150. Due to the random elements of the model, this value will differ between users.

A224 When the number of animals is much higher, the standard deviation will be smaller, so the line will be smoother.

Decision analysis (filename: DECANAL.WK1)

A51 The payoff of the different strategies is based on the following assumptions: the value of an average cow (with no displaced abomasum) = COC + SV.
When a cow has got displaced abomasum, and you choose 'no surgery' the value of the cow decreases to only the slaughter value (SV).
After successful 'surgery' the value of the cow is again COC + SV, but you have incurred the expense of the surgery, so the payoff is COC + SV - SCa(i).

When 'surgery' fails, the value of the cow decreases to SV (when the meat is not condemned) or even to 0 (when the meat is condemned). There is also the cost of the surgery, so the payoff of an unsuccessful surgery is 'proportion not condemned' x SV - SCa(i).

D76 The EMV of a1 is US$889, of a2 US$892 and the EMV of a3 is US$800. Strategy **a2** has the highest EMV and is the optimal strategy according to this strategy.

G97 The maximin criterion judges a strategy on its worst payoff:
Strategy a1: US$505
Strategy a2: US$60
Strategy a3: US$800.
a3 has the highest 'worst payoff' and is the optimal strategy according to the maximin criterion.

F105 Minimax regret:
Strategy a1: US$295
Strategy a2: US$740
Strategy a3: US$300.
a1 has the lowest 'maximal regret' and is the optimal strategy according to the minimax regret criterion.

F114 The maximax criterion judges a strategy on its best payoff:
Strategy a1: US$985
Strategy a2: US$1100
Strategy a3: US$800.
a2 has the highest 'best payoff' and is the optimal strategy according to the maximax criterion.

C139 **B**: the decision maker is risk averse.

C153 U(x) = 100 - (100^2) / 4000 = **97.5**

D153 U(x) = 500 - (500^2) / 4000 = **437.5**

E153 U(x) = 900 - (900^2) / 4000 = **697.5**

A158 Option (a) gives a utility of 437.5. Option (b) gives a utility of 0.5 x 97.5 + 0.5 x 697.5 = 397.5. Option **a** has the highest utility, so **a** will be preferred.

D163 The farmer is risk **a**verse, because (s)he prefers US$500 for sure to the uncertainty of 50/50% probability of US$100 / US$900.

D171 **B**: EMV is a risk-neutral criterion.

D178 **D**: all the answers are correct.

D194 **a1**: this strategy has the highest utility.

G257 The probability of success when the veterinarian gives the forecast that the surgery will fail = P(Success|z2). This value is given in the table (in cell G253): **0.57**.

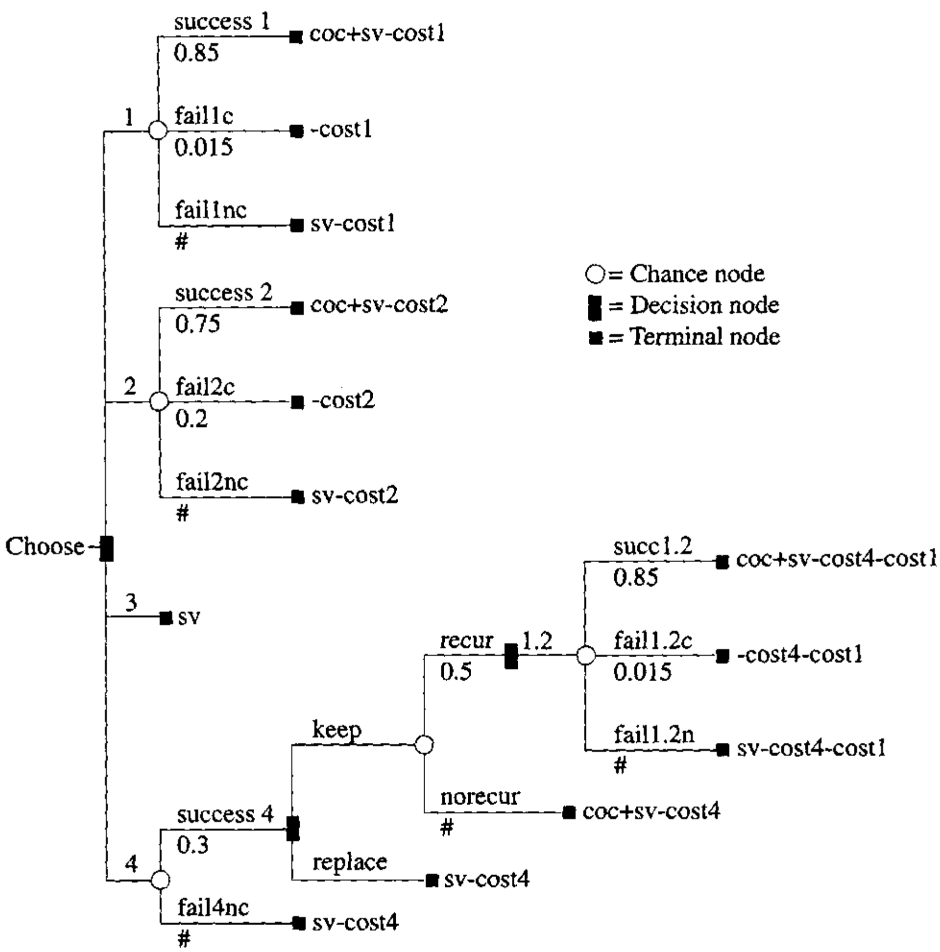
D268 The monetary value of a1, given forecast z(1), is the Posterior Probability for this situation multiplied by the profit from the strategy, summed for success and failure. This is:
C216 x F253 + C217 x F254 = US$970 x 0.89 + US$490 x 0.11 = US$**917.20**.

F297 **Y**es: the EMV with forecast is higher than without one:US$917.80 (cell E293) and US$892 (cell D87) respectively, so the forecast is worth its money.

F304 You have to change cell C209 (= price of a forecast) to US$50. Now the EMV with forecast is US$882.80. The EMV without a forecast is still US$892, so the forecast is too expensive to be worth it. The correct answer is **no**.

Decision-tree analysis (filename: DECTREE)

1. The program shows EU(keep) etc. In our case we do not work with utility, so the given values are EMVs. The EMV of 'keep' is US$996.5, the EMV of 'replace' is US$740. 'Keep' has the highest EMV, so the farmer should decide to keep the cow.
2. On the following page a printout is given of the entire tree.
3. EMV of strategy a1 = US$913
   EMV of strategy a2 = US$840
   EMV of strategy a3 = US$800
   EMV of strategy a4 = US$816.95
   The optimal decision is strategy a1.
4. The variable coc: this value gives the profit from keeping a cow compared with replacement. When a cow produces below average, she will yield a low profit on keeping, so a low coc.
5. The threshold of coc is US$267.06. This means that when coc is US$267.06 the profit from culling the cow is equal to the profit from strategy a1. A coc lower than the threshold means that culling is more profitable than strategy a1.
6. The graph you see gives the relation between the costs of strategy a1 and the threshold of coc (where culling is equal to strategy a1). When the costs of strategy a1 are quite high, the cow has to produce very well to make it worthwhile to choose for surgery. So, higher values of cost1 give higher thresholds of coc.
8. When the probability of success of rolling is 0.68 or more, rolling is the most optimal strategy.
   The graph shows the EMVs of all four strategies (the first character of the name of the strategy is given), dependent on the value of the probability of success of rolling (prob4). The EMVs of strategies a1 to a3 do not differ when prob4 increases but the EMV of strategy a4 increases when the probability of success increases.


success 1
0.85
coc+sv-cost1
1
fail1c
0.015
-cost1
fail1nc
#
sv-cost1
success 2
0.75
coc+sv-cost2
2
fail2c
0.2
-cost2
fail2nc
#
sv-cost2
Choose
3
sv
succ1.2
0.85
coc+sv-cost4-cost1
recur
0.5
1.2
fail1.2c
0.015
-cost4-cost1
keep
fail1.2n
#
sv-cost4-cost1
norecur
#
coc+sv-cost4
success 4
0.3
replace
sv-cost4
4
fail4nc
#
sv-cost4
= Chance node
= Decision node
= Terminal node

Index