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EPIDEMIOLOGICAL WORKSHOP

A CASE STUDY OF
BOVINE VIRUS DIARRHOEA

TECHNICAL ASPECTS OF BOVINE VIRUS DIARRHOEA

J.W. HARKNESS*

Most scientists concerned with the control of animal diseases would agree that it is essential to have a valid understanding of the epidemiology of any disease before attempting to design and implement control schemes. In the case of Bovine Virus Diarrhoea (BVD), substantial areas of economic loss resulting from infection with the causative virus (BVDV) have for many years been inadequately appraised; more importantly, a widespread failure to recognise the significance of facets of the epidemiology which are of central importance has considerably delayed the development of efficient control measures.

Until recently, the prevailing view of BVD was of an acute viral disease of cattle, usually mild and of short duration, which only occasionally caused appreciable economic loss; however, sometimes the virus was associated with outbreaks of a clinically and pathologically dramatic disease of growing cattle, known as Mucosal disease (MD), in which case-mortality rates were high and economic losses were substantial. MD was not reproducible in the laboratory and could not be accounted for in terms of sudden changes in virus virulence. The relationship between BVDV and these two dissimilar conditions remained an enigma.

CURRENT CONCEPTS OF THE EPIDEMIOLOGY OF BVD

The very first account of BVD in the field (Olafson et al., 1946) makes reference to the fact that abortions were a feature of the clinical picture and this observation was confirmed by later workers (Dow et al., 1953; Huck, 1956). Fetopathy caused by BVDV has been recognised for many years. Experimental investigation of BVDV-induced fetopathy started in the early 1970s, but it is only relatively recently that the results of experimental and observational studies at several laboratories worldwide have been assembled into a concept which indicates the central importance of fetal infection in the biology of the virus. It was through these investigations that the most significant advances of recent years were made. The key findings to emerge include :

High efficiency of transplacental spread: Unlike the situation encountered in certain other viral infections affecting the fetus, experimental exposure of non-immune pregnant cattle to BVDV showed that spread to the fetus occurs in nearly every case.

Variety of sequelae, depending on gestational age at infection: The outcome of fetal BVDV infection is largley dependant upon fetal age at exposure; within affected herds (any or all of) repeat breeding, abortion, stillbirth,

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congenital abnormalities, retarded growth, and MD (see 4. below) may occur. The variety and frequency of the sequelae provide insight into the extent of the associated economic losses.

Occurrence of persistent infection with BVDV: Experimental infections showed that infection of the bovine fetus with BVDV at between 45 and 125 days gestation resulted in lifelong infection with the virus and failure to develop anti-BVDV antibody even in postnatal life. Unlike the 'carriers' in other diseases, these persistently infected individuals were shown to have virus in many tissues and organs, and to continually shed virus in bodily excretions and secretions. They are key individuals in the spread of infection within and between herds.

Persistent BVDV infection is an essential prerequisite for the development of MD: This conclusion explained for the first time the apparently anomalous epidemiology of MD and the association of BVDV with both of the clinically dissimilar conditions, BVD and MD. It appears that between 40% and 50% of all persistently infected calves born develop MD in the first two years of life.

Persistently infected cattle can breed: Although many persistently infected calves show poor growth rates and may succumb with MD, some grow normally and may survive to enter the breeding herd. Calves born to these individuals are usually themselves persistently infected and by this means the virus is perpetuated into following generations.

Related pestiviruses of other species can infect cattle: Experimental studies in pregnant sheep with BVDV, and in pregnant cattle with the virus of Border disease of sheep showed that cross-infection was possible, in both directions, and consequences were closely similar to infection with the 'homologous' virus. Similar pestiviruses were also found among deer and goats.

These and other findings are embodied in a conceptual model of the disease which distinguishes the effect of postnatal BVDV infections from those of prenatal BVDV infections. As before, the available evidence indicates that most postnatal infections are inapparent and clinical BVD, when it occurs, is usually of a trivial nature and short duration. A minority of virus strains may be more virulent. In addition, in some circumstances interaction with other infectious agents may lead to development of serious clinical disease; calf respiratory disease is of importance in this connection. BVDV may also potentiate the spread of primary viral pathogens, including IBR virus (Edwards et al., 1986).

As far as prenatal BVDV infections are concerned, the variety of possible outcomes for the fetus has already been mentioned, and the results of experimental infection have defined, in most cases, the gestational age(s) at which each of the possible outcomes occur; this makes it easier to estimate economic costs for affected herds. Discussion of the costs of BVDV infection follow in later contributions. It is sufficient to notice at this point that within individual herds, particularly closed herds of non-immune cattle to which the virus has been recently introduced, the losses may be widespread and the economic costs financially devastating. In a published study in which a dairy herd was observed in detail over a period of time, the financial loss was assessed at between £2,300 and £4,115 (Duffell et al., 1986). The case for better methods of control is made clearly by examples of this kind.

DIAGNOSIS AND INVESTIGATION ON FARMS

Investigation of BVD on many farms shows that a diagnosis is frequently not reached until many months after the majority of new infections have occurred. For farmers and veterinary surgeons one of two events most commonly indicates the presence of BVDV infection in the breeding herd. They are :

Multiple abortions of unexplained aetiology: Abortions may occur early in gestation (at 3-5 months) or later (at 7-8 months). In early abortions an autolysed fetus is expelled within a few weeks of infection in early to mid-gestation. BVDV is not usually isolated from the abortus but antibody to the virus may be present in some cases. Late abortions are characterised by the expulsion of a fresh fetus which is positive for BVDV but antibody negative. Establishing an aetiological role for the virus in these circumstances is often difficult, and it may be impossible to confirm a diagnosis unless material is collected from several abortions.

The occurrence of Mucosal disease: One or more cases of MD may be diagnosed on the basis of clinical signs and post mortem findings, confirmed by laboratory tests. A full herd history is assembled and the timing of active infection can often be established on the basis that the dams of the MD affected calves become infected with BVDV at between 45 and 125 days of pregnancy.

Full or partial herd screening is required in both situations in order to identify persistently infected cattle and to discover the current antibody status of the population. This part of the investigation is vital to decision-making regarding future control of disease. In many herds, most of the losses resulting from infection of adult cattle will already have been incurred by the time of diagnosis; the object of control measures is therefore to minimise losses from future infections on a cost-effective basis.

CONTROL OPTIONS AND THEIR LIMITATIONS

Preliminary estimates indicate that on a national scale the great majority of BVDV-associated economic losses are the result of prenatal infections (Harkness 1987). The primary aim of control in breeding herds should be the prevention of such infections, and its achievement can be expected to result in the elimination of BVDV-induced reproductive losses and, by avoiding the birth of persistently-infected calves, the prevention of losses associated with poor liveweight gain and with MD. Effective control requires the removal of persistently-infected cattle from the breeding herd, and

either (i) that all sources of BVDV infection are eliminated from the farm,

or (ii) that only immune animals are introduced and bred.

In rearing enterprises employing market purchased calves the former (option (i)) is usually impractical. In attempting to reduce the direct and indirect impact of primary postnatal infections the only practical approach is that of artificially boosting levels of immunity.

In general, while there are a number of variations on the main themes, control strategies of three types have been proposed. The first of these might be described as 'considered inactivity' and represents the non-intervention option. This policy is tenable only where the virus has spread rapidly through the breeding herd stimulating protective immunity in a high proportion of animals and further losses are improbable. It can be argued that non-intervention has often been the policy in the past, because of an incomplete knowledge of BVD, with less than dire consequences. However, it represnts a gamble, since there are well documented instances in which within-herd spread of BVDV was slow, encompassing more than one breeding season (Barber et al., 1985). In dairy herds with high replacement rates susceptible populations build up rapidly and these herds are liable to continuing economic loss. Without comprehensive serological screening, 'considered inactivity' has unpredictable consequences and could result in perpetuation of BVDV problems.

The remaining two types of strategy are the 'test and cull' and 'vaccination-based' control programmes, each of which involves active intervention in an attempt to reduce further losses.

'Test and cull'

'Test and cull' programmes aim to identify persistently infected cattle, to remove them from the breeding herd or isolate them, and subsequently to maintain the herd BVDV-free. Programmes of this type require that all cattle destined to enter the herd are isolated and shown to be free from BVDV before joining it. The problems presented by such programmes include :

Limited application: As noted above, 'test and cull' strategies are unworkable in some types of enterprise, particularly rearing units.

Dependance upon laboratory testing: The strategy relies entirely upon the availability of accurate and cheap laboratory tests. It is completely undermined by false-negative virus detection tests; although these are not known to occur it is overly optimistic to assume that any laboratory test is 100% accurate.

Maintenance of BVDV-free status: The 'test and cull' strategies create antibody-free herds, vulnerable to extensive losses if BVDV is accidentally reintroduced. Prevention of reintroduction requires that the farmer has a thorough working knowledge of possible sources of infection, and his awareness of the problem must be carried into the long term. In practice it may be difficult to avoid contact between susceptible cattle and sheep or deer, which could be carrying BVDV. In addition, routes of introduction (e.g. needle transmission) may be outside his direct control.

'Vaccination-based' strategies

The objective of these strategies is to create an immune breeding herd by vaccinating heifers before first mating so that the fetus is protected. The current problems inherent in this approach are :

Adverse reactions: Many existing modified live BVD vaccines are thought to induce serious adverse reactions. Vaccine viruses have been shown to cross the placenta in pregnant cattle causing all the fetopathic effects observed after infection with field strain virus (Liess et al., 1984). These vaccines should therefore never be used in early pregnancy. The use of live BVDV vaccine in calves has been shown to have serious deleterious effects on health (Terpstra et al., 1982; Martin, 1983). Some of these ill effects may result from potentiation of intercurrent infections, arising from the immunodepression caused by BVDV, but losses are also attributed to vaccination of persistently infected calves; this practice appears to precipitate MD in a proportion of cases (Peter et al., 1967).

Vaccine availability: BVDV vaccines suitable for protection of breeding cattle are not licensed for use in the U.K. at the present time.

Vaccine efficacy: Although most of the economic costs associated with BVDV follow from fetal infections, licensing authorities have not in general required evidence from manufacturers of ability to protect the fetus. The status of most existing vaccines is therefore unknown in this respect.

Vaccinal cross-protection: Antigen variation if known to occur among BVDV field strains. There is some evidence of good cross-protection between widely different strains from experimental postnatal infections in calves (Castrucci et al., 1978) but it is not yet clear that this extends to protection for the fetus. A vaccine containing a single strain of virus may or may not provide cross-protection against a full spectrum of BVDV field strains (including those from sheep and other hosts) in the context of fetal infections.

A comparison at current costs of the likely financial inputs to each of the latter two types of strategy suggests that the initial outlay for the farmer may be similar. However, a vaccination policy is clearly easier to operate efficiently, and generates an immune herd, which incurs fewer extra labour costs arising from the need for special management practices designed to prevent re-introduction of infection. Vaccination can be employed in both breeding and rearing enterprises and involves much less technically intricate and expensive laboratory testing. Furthermore, the present known failings and reservations concerning existing vaccines can be tackled through appropriate research and development; the problems arising in 'test and cull' programmes are clearly much more intractable. For these reasons there can be little doubt that the application of vaccination-based strategies offers a better solution to future BVD control than the alternatives.

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EPIDEMIOLOGICAL METHODS AND THEIR APPLICATION TO BOVINE VIRUS DIARRHOEA VIRUS

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The descriptive epidemiology of BVDV has become much better understood in recent years, and at the same time concern has increased about its possible significance in the cattle population. This probably arises from two observations - one is a better understanding of the relationship between exposure to the virus and its clinical and subclinical effects, and the other is the realisation that the great majority of cattle in the UK and in most European countries have experienced infection. Taken together, these give a picture of a disease which, while normally of little apparent consequence, can cause severe losses in some cases and may be the cause of a substantial total loss to the industry.

The problems facing us are thus to provide the basis for rational advice to herd owners on avoidance of BVDV related losses, and to get a better view of the overall significance of such losses. In order to achieve either of these we need to advance our knowledge of the quantitative epidemiology of BVDV in the cattle population as presently managed.

WHAT WE MIGHT HOPE TO ACHIEVE

Such advances should have benefits not only in providing improved estimates of overall losses and the risk faced by individual herds, but should also give a basis for predicting the effects of national or local control measures. These are quite unclear at present - for example, it is not certain whether it is better to advise a herd owner to take steps to exclude BVDV from his herd, thus avoiding the small losses but laying himself open to a major outbreak, or to cause it to persist and thus maintain his herd's immunity.

A quantitative description of the circulation of the virus might even be able to distinguish between the relative frequency of different pathways of infections. For example, the relative significance of spread from acutely infected cattle to that from persistently infected cattle is not certain, though it is thought to be small.

WHAT WE HAVE

The information from which we start to explore the quantitative epidemiology of BVDV is of two types. There is information from experimental studies of infection and field observations, and a certain amount of information from surveys of serological and virus prevalence.

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Experimental results and field observations

The present understanding of the epidemiology of the virus has already been described and is well summarised elsewhere (Nettleton et al, 1986; Duffell and Harkness, 1985). To simplify greatly, it appears the remarkable feature of the transmission of the virus is that if a pregnant cow is infected then the fetus will also be infected, and if this occurs before about 120 days of gestation then the fetus becomes "persistently infected" (PI) and carries and excretes virus throughout its subsequent life. The dam develops an immunity which appears to be lifelong, as does any other infected bovine or a fetus older then 120 days whose dam becomes infected. Infected animals excrete virus briefly but may well be an insignificant source of infection in comparison with PI animals, which quickly infect any animal in contact. Calves of PI cows are themselves PI. Immunity can be determined by serological test and PI animals can usually be detected by isolation of virus from a blood sample.

Still simplifying, losses associated with BVDV infection are of three types. Firstly, PI animals are generally of reduced growth, production and fertility and may succumb to mucosal disease, a fatal condition peculiar to such animals. Secondly, acutely infected animals are briefly ill from the virus but more importantly they are also briefly immunosuppressed which makes them susceptible to any other pathogen to which they may be exposed. Thirdly, the infection of a pregnant cow can have consequences for the fetus other than persistent infection, such as abortion, stillbirth, growth retardation and congenital defects.

Serological and virus survey results

In England and Wales, Harkness et al (1978) reported an antibody prevalence of 62% based on samples collected under the Brucellosis Eradication Scheme, and more recently Edwards et al (1987) reported a prevalence of 65% based on diagnostic submissions. In Scotland, Nettleton et al (1986) report a prevalence of 63%, also based on diagnostic submissions. Outside the UK, Meyling (1983) found 78% of cattle in two slaughterhouses in Denmark seropositive. Of these reports only Harkness et al (1978) was able to give any relationship with age, in the light of which Meyling's result is found to be consistent with that found in older cattle. Bolin et al (1985) found 89% of cattle positive in 66 herds in Mid-West and Western USA, some of which were selected because of a BVD history.

Meyling (1983) found 0.9% of cattle viraemic and Edwards et al (1987) found virus in 1.8% of samples received for what are thought generally to be preventive screening. Howard et al (1986) in the UK found virus in four of 666 calves (0.6%) though two subsequently seroconverted, so only 0.3% were persistently infected; one of 93 cows (1.1%) and one of 165 gnotobiotic calves (0.6%) were persistently infected.

WHAT IT MEANS

The brief description of the epidemiology of BVDV given above is in two parts - the first describing the transmission of the virus and the second the associated losses. If we know the frequency of transmission then the frequency of loss follows fairly readily; for example, we know the likely effect of infection of a pregnant cow on its fetus in terms of gestational age, so it is only necessary to determine the incidence of infection specific to each age of gestation to determine incidence of the various sequelae. Likewise, the incidence of acute infection gives the total incidence of losses associated with the acute illness of the animal, although further investigation is needed to determine the distribution of type and severity of loss. Finally, it is the relatively enhanced mortality (natural or from culling) of the persistently infected animal that determines much of the loss directly associated with such animals.

Prevalence surveys do not directly provide sufficient information for estimating the incidence of infection or mortality, but they can provide a basis for such estimates and it is worth considering how this can be done.

Catalytic models

In examining the kinetics of a catalytic chemical reaction, the reaction is stopped at various times and the proportion of substrate converted is measured, and by fitting a suitable curve to the results the rate of conversion may be estimated. In a similar way, in a susceptible population which is suddenly exposed to a simple infectious disease, the incidence can be determined from the prevalence of immunity at various times, or alternatively if the disease is endemic the incidence can be determined from from the age specific prevalence of immunity at one time. (Muench, 1959; Griffiths, 1974).

The possibility of applying the method to BVDV was first noted by Done et al (1980) who observed that the age-specific prevalences reported by Harkness et al (1978) implied that some 39% of cows had been infected during their first three pregnancies, and taking the fetus to be vulnerable to complications for 180 days per year then the incidence of such complications must be about one in 16 births.

The data of Harkness et al (1978) is shown in Table 1.

Table 1: The relationship between age and antibody prevalence

Age of animal (years)	1	2	3	4	5	>5	Total
Number of SN tests	84	241	236	250	159	473	1443
% positive (> 1/10)	25.0	41.0	52.5	72.0	71.7	76.9	62.5

The incidence during any year of life can then be inferred from the table by subtracting the prevalence at one age from the next, thus between 2 and 3 years old, the incidence seems to be on average 52.5 - 41.0 = 11.5 percent per year. If we start at 2 years old and keep a cow for 5 years, she will experience incidence rates of 11.5%, 19.5% and then say (76.9 - 72)/3 = 1.6% per year for 3 years. Done et al (1980) considered only 3 years and were concerned with any fetal complication, but if we confine ourselves to the incidence of the birth of PI calves to non-PI cows, which is the likely result of infection between about 40 and 120 days of gestation, then our 5-year cow, if producing one calf per year, has a chance 80/365 times the incidence for each year of producing a PI calf or an total of 80/365 x (11.5 + 19.5 + 1.6 + 1.6 + 1.6) = 7.9%. This is over five calves, so we expect the proportion of PI births to be 1.6% of births, and the incidence of other complications can be similarly estimated.

This approach is a useful first step and shows the enormous value of collecting age-specific data. The accuracy cannot however, be claimed to be very high due to the difficulty of determining a "start point" for the cow for her first pregnancy since ages are only recorded to the nearest year, and more importantly the fact that assuming an even incidence over each pregnancy ignores some well known facts of cattle management. It is likely that much acute infection, at least in dairy herds, is associated with introduction of new calved heifers to the adult herd and if this occurs (as one would expect) at a time when most of the adults are in late pregnancy or newly calved then the assumption of an 80/365 chance of infection resulting in birth of a PI calf is a great overestimate.

Model of herd incidence

Before the significance of PI animals was understood, Kahrs et al (1966) proposed a simple model for the prevalence of BVD immunity. Outbreaks of infection occurred at random intervals in a herd, resulting in an immediate prevalence of immunity of 1 followed by a steady decline of 0.2 per year as immune animals are replaced by susceptible herd recruits until after 5 years the herd reverts to complete susceptibility, unless another outbreak intervenes. Robson et al (1967) showed how the likely interval between outbreaks could be inferred from the prevalence of immunity in a survey of several herds, and Taylor (1968) showed, under a slightly more general replacement model, how to optimise a vaccination programme.

The rapid development of immunity in a herd is what we would expect following introduction of a PI animal, but the decline in herd immunity would not begin until that animal, and any other PI's it may have engendered, left the herd.

The incidence of herd outbreaks is an important measure of the risk to individual herds and development of a more realistic model of the course of infection within a herd offers a mean of asessing that risk.

A compartmental model of virus circulation

We can draw up a diagram (Fig. 1) of the three possible states of an animal with respect to BVDV: PI, susceptible and immune, and show the transitions between them in the manner of many compartmental models of human infections (Anderson and May, 1983).

We have left out the infectious stage between susceptible and immune, assuming this for the present to be insignificant.

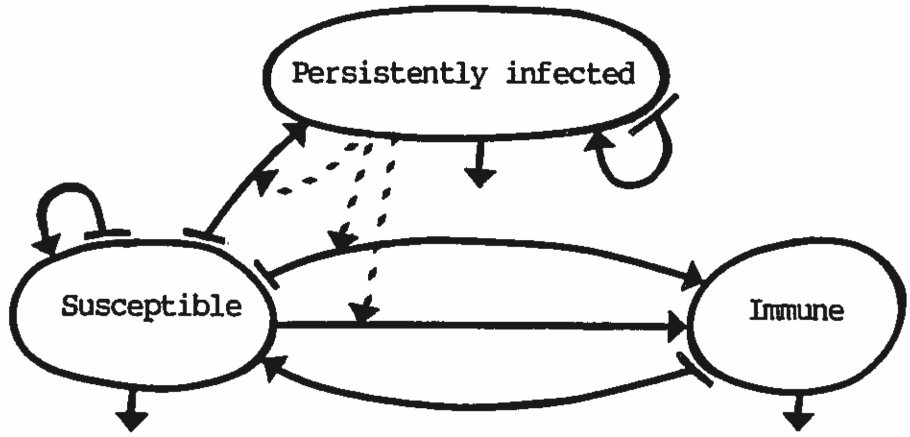

Fig. 1 Diagram of the possible states of a cow with respect to BVDV, and the transitions between them.

Key: ⟶ state changes of born animals
⟼ state of offspring at birth relative to dam
⇢ influence of one class on a transition

The diagram shows most of the features of the cycle of infection except that the timing is a little imprecise; PI or immune calves are born to immune, not susceptible dams but the dam must have become immune during the gestation.

In a freely mixing population it would be possible to attach labels to the transitions of the diagram and write down a set of equations connecting them that would make a mathematical model of the disease.

The separation of cattle into herds and their management, which removes calves from their herds of origin either permanently or temporarily, makes this impossible. However, one can write down some relationships which must hold in order for the disease to be in a stable endemic state; in particular, for the number of PI's to be constant we must have the two inward flows balancing the one outward flow from the class, in other words

$$m_p = c \times b_s \times s + b_p$$

where m_p is the per capita mortality rate of PI's (whether by natural death or culling), b_p and b_s are the per capita birth rates of PI and susceptible cattle, $\check{s}$ the number of susceptible cattle, and c is the number of "effective contacts" per unit time per PI per susceptible which result in the birth of a PI animal.

Since b_s is the same as the normal birth rate b, or the normal death rate m, it follows that

$$\frac{m_p}{m} = c \times s + \frac{b_p}{b}$$

or in its relatively shortened herd life ($m_p > m$), the PI cow must replace itself either by its own offspring or by causing a susceptible cow to give birth to a PI calf.

WHAT WE NEED

To estimate total losses

In order to provide information sufficient for an economic analysis of total losses as has been reported in the past (Bennett and Done, 1986; Spedding et al 1985), the main requirement seems to be for better estimates of incidence of infection specific to each stage of gestation, and for information on the longevity of PI animals. Both these can probably best be derived from appropriate surveys.

The incidence of infection can be inferred from a serological prevalence survey as described, provided that age, parity and stage of gestation are recorded for each sample. In a similar fashion the longevity of PI animals can be determined from their age-specific prevalence in the general population, since the age structure of the cattle population is reasonably well known.

When a PI cow dies of mucosal disease, the losses are of two sorts. One arises from her premature removal from the herd, and is the same as the cost of any culled cow, and the other is the additional cost from having this happen at a time not planned by her owner. Only if this second aspect of the cost is thought to be significant do we need to concern ourselves about the incidence of mucosal disease. If it is significant then a study of the age of mucosal disease cases is required to supplement the prevalence survey.

The most difficult aspect of loss to estimate is that associated with acute infection, although its frequency can be determined. It is necessary to know times of infection in order to determine any associated loss of production. An examination of the milk production records of herds where an outbreak can be identified to the import of a PI cow would provide one aspect of the loss.

To estimate the risk to individual herds

The information necessary to assess the risk to an individual herd owner is of two sorts - the likelihood of his herd becoming infected and the likely effect in his herd.

The likelihood of herd infection probably relates mainly to the chance of purchasing a PI animal, and information on their age prevalence together with the herd owner's purchasing policy will be sufficient to determine this although it should be noted that there may be some regional variation in prevalence.

The effect in the individual herd will depend on time of infection, separation of stock on the farm, and the initial level of immunity. To predict the effect further will require a computer model of the herd such as that used for brucellosis (Hugh-Jones et al 1975) or preferably a modification of one of the models recently developed which incorporate production effects (Morris and Marsh, 1984; Dijkhuizen et al 1986). This model must be capable of allowing for whatever control measure is envisaged, whether vaccination or separation or natural exposure of young stock. The likely longevity of PI animals will be important in determining the likely course of the disease in the herd.

The risk to the individual herd from sources other than introduction of a PI animal is difficult to assess directly. It is not likely to be of a high probability so a case-control study relating to risk factors such as presence of sheep would have to be large.

An alternative approach to the assessment of risk other than from PI animals is suggested by Kahrs' model. If the likely course of a herd outbreak can be predicted then serological prevalence data can be used to estimate the actual frequency of herd infection, and this may be compared with the frequency predicted from study of cattle movements, together with age related prevalences of PI animals. There seems to be very little data presently available on cattle movements on which to base such a comparison.

To predict national effects of control

If it should be possible to produce a satisfactory synthetic model of virus circulation in terms of observations of animal movements and management then this may have benefits beyond simply assessing risk from sources other than PI animals.

Much of the losses from BVDV, as well as the means of maintenance of the virus, are associated with infection of susceptible cattle during pregnancy. Knox (1980) pointed out, in the related problem of rubella in humans, that vaccination of children can act to increase the incidence of infection among pregnant women and it may be that use of vaccination or other preventive measures in individual herds would increase losses to other herds by reducing immunity among heifers becoming pregnant for the first time.

In order to predict the effects on the national herd of control exercised in a limited number of herds, all the missing pieces of information described above will have to be determined, that is

(i) the longevity of PIs
(ii) a model of disease within a herd
(iii) knowledge of inter herd movements

CONCLUSION

It would appear that much could be added to our knowledge of BVDV losses by careful surveys of the division of the population into immune, susceptible and PI at different ages, and stages of pregnancy. To take this further and complete the cycle in quantitative terms requires more detailed knowledge of national management and movement practices. This is true of most farm animal disease and causes Beal (1983) to inveigh against "pseudo epidemic models" which do not properly allow for both within and between herd spread, so that the effects of control cannot be properly estimated.

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THE ECONOMICS OF THE BOVINE PESTIVIRUS SYNDROME AT FARM LEVEL

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The Bovine Pestivirus Syndrome (BPS) comprises all the clinical and pathological sequelae of infection of cattle by the bovine diarrhoea virus (BVDV), a member of the genus Pestivirus, family Togaviridae. Its manifestations range from clinically inapparent infection to death, and include transient diarrhoea, foetal dysgenesis, abortion and so-called mucosal disease.

Increasing awareness of this syndrome and its incidence has directed attention towards the likely costs of the disease and the means of controlling it. Provisional estimates by Bennett and Done (1986) based on the information then available, put the annual national cost at some £47 M: and this did not include disruption of management and markets and the wider economic effects. In the absence of specific means of prevention and treatment, possible alternative strategies for control of the disease syndrome in Britain have assumed greater importance.

In previous papers (Spedding et al. 1985: Bennett and Done, 1986), we explored in outline some of the more obvious control strategies which might be applied at national level, using a cost-benefit approach. From our limited studies we tentatively concluded that, for a number of reasons, no clear and obvious national control policy already existed or seemed likely to emerge in the near future.

However, farmers and producers are likely to hear more and more about this disease complex. Producers are then going to be asking (a) how much of a threat or potential threat is this disease to my herd, (b) how do I know if or when I've got a problem and (c) should I do anything about it, if so, what should I do and when? The answers to these basic but important questions are likely to vary depending on the producer himself, and the nature of his farm business. In this paper therefore we have tried to look at the control of BPS essentially from the viewpoint of the individual cattle farmer.

APPROACH AND METHODOLOGY

The producer is a decision maker hoping to make a rational optimum/best choice from among various possible options. In order to make such a choice, the producer needs to know what strategies or options are open to him together with the likely 'pay-off' of each strategy in terms of the advantages or disadvantages (costs and benefits) of each. Before investigating the possible strategy options toward BPS, one obvious choice is to 'do nothing' and 'hope for the best'.

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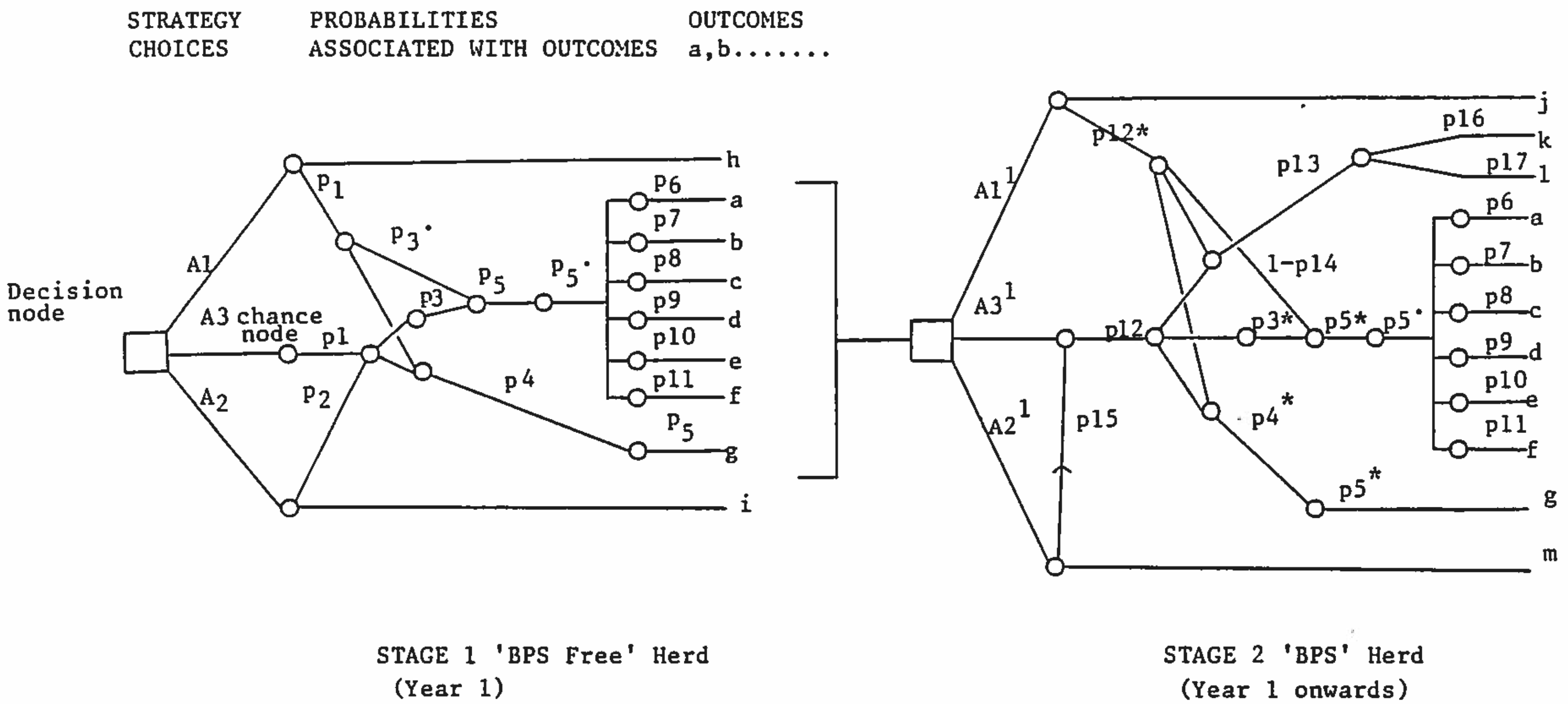
Many farmers will have already adopted this strategy passively, without information regarding the risks of infection to their cattle, the possible or likely losses (costs) involved should infection be introduced or even the possibility that the disease could already have been introduced into their herds.

To explore the strategy options toward BPS that producers might choose from and to provide a framework for decision making for farmers and advisers, a simple methodology has been followed by the authors. It incorporates elements of 'process charts' showing the essential sequence of stages of infection of a herd by the bovine pestivirus; of 'decision analysis' in the form of a decision tree giving the outcomes of any action and their probabilities of occurring; and of financial cost-benefit analysis in the form of valuations of outcomes. Figure 1 shows the basic decision tree used for BPS, with Tables 1 to 4 providing a key to the diagram and showing the methodology of the analysis. The model has been linked to a computer spreadsheet to enable rapid calculations of different situations to be made.

Only three strategy choices have been considered at two stages, although other strategies can be relatively easily added to the analysis. The decision tree has two points of decision making or 'decision nodes', one before the introduction of disease to a herd (ie. a 'disease free herd'), Stage 1, and another, Stage 2, following initial disease problems experienced by a herd. From the first decision node three althernative courses of action are considered; 'do nothing', 'vaccinate prophylactically' and 'ensure disease free replacement stock'. The possible outcomes of each of these courses of action or strategies, depend on a number of factors. These are taken into account by the use of chance nodes and probabilities. For example, the outcome of foetal death or abortion of cows due to BPS (outcome a) depends on the likelihood or probability (i) of the herd being exposed to the disease virus (P1), (ii) that cows are susceptible (ie. non-immune) to infection (P3) (iii) that infection is established (P5) and (iv) that the cow is infected during a critical stage of pregnancy (P5° and P6). Many of the probabilities or measures of likelihood will vary from herd to herd, being dependent on the systems of production used, the health status of herds and so on, and will vary over time.

The possible outcomes of strategies in terms of losses or prevention of losses to production and resources used in disease control are valued and presented as money values.Each strategy therefore will have an outcome measured in terms of a money value which depends on a number of factors represented by probabilities. To compare strategies, the sum of expected money values of the various outcomes associated with each strategy should be compared. The expected money value (EMV) of an outcome is the probability of that outcome occurring multiplied by the money value of the outcome. Thus, the expected extent of physical losses to production caused by BPS will vary according to the values given to the various chance probabilities. The highest possible values that are thought likely for these probabilities will result in an EMV which represents the highest losses (ie. the worst situation or outcome) which a farmer could expect from selecting a particular strategy. The resultant EMV's for each strategy will vary according to differing assumptions regarding disease status of herd, management and production systems, herd size and so on, which are internal to the farm enterprise, as well as those external to the farm such as efficacy of disease control aids (eg. vaccine), disease status of livestock markets, proximity and disease status of neighbouring livestock and so on. The values of variables in the model(eg. probabilities, number of stock etc) can therefore be varied according to the

FIGURE 1 DECISION TREE FOR BPS



The outcomes from a chosen course of action are found by following all the pathways originating from the strategy choice, moving from left to right. All outcomes encountered in this way are possible and are not mutually exclusive.

TABLE 1.

STRATEGIES Toward BPS.

Stage 1.

A1	=	Vaccinate prophylactically all females before breeding.
A2	=	Buy in disease free stock or breed own disease free replacements.
A3	=	Do nothing.

Stage 2.

$A1^1$	=	Vaccinate out of trouble; vaccinate and test for virus and antibody breeding females before next pregnancy, isolate and cull infected/non seroconverters when appropriate.
$A2^1$	=	Test and cull; test all cattle for antibody and virus - isolate and cull virus positive animals when appropriate.
$A3^1$	=	Do nothing.

OUTCOMES

a	=	Foetal death/embryo loss.
b	=	Congenital defects/deformities etc. with some neo-natal and post-natal deaths.
c	=	Retarded growth also with some neo-natal/post-natal deaths.
d	=	Birth of apparently normal calves which are not persistently infected and are virus negative, but with some post-natal deaths due to impaired immune systems etc.
e	=	Birth of apparently normal calves which are however persistently infected, with some post-natal deaths due to impaired immunity etc.
f	=	Transient BVD infection in adult cows.
g	=	Transient BVD infection in young stock, followers and other cattle.
h	=	Prophylactic vaccination of all females before breeding.
i	=	Ensuring disease free replacement stock by testing for virus and antibody, then if necessary vaccinating, quarantining and testing again. Animals which fail to seroconvert or found persistently infected would be sold or culled when appropriate.
j	=	Vaccination and testing for virus and antibody all breeding females before pregnancy. Isolation and culling of infected/non seroconverters when appropriate.
k	=	Deaths due to Mucosal Disease.
l	=	Treatment of Mucosal Disease cases.
m	=	Testing of all cattle for antibody and virus; isolation and culling of virus positive animals when appropriate.

TABLE 2.

ASSOCIATED PROBABILITIES

P.1	=	Probability (prob.) of herd being exposed to BVD virus.
P.2	=	Prob. of herd being exposed to BVD with only 'disease-free' stock being introduced.
P.3	=	Prob. of any one cow being susceptible to infection under the 'do nothing' policy.
P.3°	=	Prob. of any one cow being susceptible to infection with the 'prophylactic vaccination' policy.
P.4	=	Prob. of young stock being susceptible to BVD virus infection.
P.5	=	Prob. of establishing infection in a susceptible animal exposed to virus.
P.5°	=	Prob. of infection introduced 0-280 days gestation.
P.6	=	Prob. of a cow experiencing foetal death/embryo loss (outcome a) when infected 0-280 days gestation.
P.7	=	Prob. of birth of calf with congenital defects etc. (outcome b) when cow infected 0-280 days gestation.
P.8	=	Prob. of calf being produced suffering from retarded growth (outcome c) when cow infected 0-280 days gestation.
P.9	=	Prob. of birth of apparently normal/virus negative calf (outcome d), when cow infected 0-280 days gestation.
P.10	=	Prob. of birth of apparently normal but persistently infected calf (outcome e) when cow infected 0-280 days gestation.
P.11	=	Prob. of transient BVD infection in adult cows with established virus infection.
P.12	=	Prob. of re-exposure to BVD virus under the 'do nothing' policy (strategy $A3^1$)
P.12*	=	Prob. of re-exposure to BVD under 'vaccinate out of trouble' strategy ($A1^1$).
P.13	=	Prob. of persistently infected animals being retained in the herd (expressed as a % of animals in herd; P.12 is obviously a function of P.13).
P.14	=	Efficacy of vaccine under Stage 2.
P.15	=	% failure of test and cull strategy (ie. (1-P.15) = efficacy of 'test and cull' strategy ($A2^1$) in preventing disease effects).
P.16	=	Prob. of P.I. animals contracting and dying from Mucosal Disease (outcome k).
P.17	=	Prob. of contracting Mucosal Disease.
P.3*	=	Prob. of any one cow being susceptible to disease following Stage 1.
P.4*	=	Prob. of young stock being susceptible to disease following Stage 1.

P.5*	=	Prob. of establishing infection in a susceptible animal exposed to virus following Stage 1.

TABLE 3.

MONEY VALUE OF OUTCOMES

a	=	n1 (v1 + v2)
b	=	n1 v3
c	=	x1 n1 v4 + (1 - x1) n1 v5
d	=	n1 v6 x2
e	=	n1 v7 x3
f	=	n1 (v8 + v9)
g	=	n2 (v10 + v11)
h	=	n1 v12
i	=	x4 v13
j	=	n1 (v12 + v13)
k	=	(n1 + n2) v14
l	=	(n1 + n2) v15
m	=	(n1 + n2) v13

* no account is taken of deformed animals which subsequently die due to immuno-suppression etc., as they are assumed to be culled when appropriate.

Where:

n1	=	number of adult dairy cows in herd.
n2	=	number of young stock/followers and other cattle.
v1	=	average value of an aborted foetus/embryo.
v2	=	value of average milk loss per cow (which = average milk loss per cow in litres (l1) x value per litre(y1)).
v3	=	average loss in value of calf due to deformities + increased risk to cow of difficult birth.
x1	=	percentage of calves suffering retarded growth and not dying (hence 1 - x1 = percentage of calves suffering retarded growth and eventually dying due to BVD infection of dam during pregnancy).
v4	=	average loss of value of calf/loss in liveweight gain due to retarded growth.
v5	=	average value of calf suffering mortality as a result of retarded growth and BVD infection of dam.
x2	=	percentage of calves which are apparently normal and not persistently infected (P.I.) which ultimately die due to immuno-suppression to other diseases.
v6	=	average value of calves/adults which are not P.I. and die.

v7 = average value of calves/adults which are P.I. and die.

x3 = percentage of calves which are apparently normal but P.I. and eventually die due to immuno-suppression.

v8 = average value of milk loss per cow due to transient BVD infection (= average number of litres per cow(12) x value per litre (y1)).

v9 = average cost of medication administered per cow where BVD symptoms are apparent (although not necessarily recognised as BVD).

n2 = number of young stock/followers/other cattle.

v10 = average value of loss in liveweight gain of young stock, other cattle etc. (= average loss in gain in kg. (13) x value per kg (y2)).

v11 = average cost of medication of young stock/other cattle with transient BVD.

v12 = cost of BVD vaccination per cow.

x4 = number of replacements/new stock.

v13 = cost of testing and ensuring disease free.

v14 = average value of animal dying of Mucosal Disease.

v15 = average cost of medication to cattle with Mucosal Disease + loss in value.

TABLE 4.

EXPECTED MONEY VALUES OF OUTCOMES

Stage 1.

Strategy A1 - Vaccinate prophylactically all females before breeding.

$$EMV1 = P1\ P3^{\circ}\ P5\ P5^{\circ}\ (P6a + P7\ b + P8c + P9\ d + P10\ e + P11\ f + A3^{1}) + P1\ P4\ P5\ g + h$$

Strategy A2 - Buy in disease free stock or breed own disease free replacements.

$$EMV2 = P2\ P3\ P5\ P5^{\circ}\ (P6a + P7b + P8c + P9d + P10e + P11f + A3^{1}) + P2\ P4\ P5\ g + i$$

Strategy A3 - Do nothing.

$$EMV3 = P1\ P3\ P5\ P5^{\circ}\ (P6a + P7b + P8c + P9d + P10e + P11f + A3^{1}) + P1\ P4\ P5\ g$$

Stage 2.

Strategy $A1^{1}$ - Vaccinate out of trouble.

$$EMV4 = \left[P12^{*}\ ((1-P14)\ P5^{*}\ P5^{\circ}\ (P6a + P7b + P8c + P9d + P10e + P11f) + P12^{*}\ P4^{*}\ P5^{*}\ g\right] x\ 2 + j + (1 + (1-P14))\ P12^{*}P13\ (P16k + P17l).$$

Strategy $A2^1$. - Test and cull.

$$EMV5 = m + (P15\ A3^1)$$

Strategy $A3^1$ - Do Nothing.

$$EMV6 = \left[P12\ P13\ (P16k + P17l) + P12\ P3^*\ P5^*\ P5^\circ\ (P6a + P7b + P8c + P9d + P10e + P11f) + P12\ P4^*\ P5^*g\right] \times 2$$

individual characteristics of the farm business and so can, to a certain extent, provide a decision tool applicable to a particular herd or farm.

RESULTS OF A HYPOTHETICAL EXAMPLE

The general model of Figure 1 was used to look at the example of a dairy herd of 100 cows and followers, with replacement stock being occasionally bought in. Details of the analysis are available as an appendix to this paper, with the values of the variables that were used shown. The probability values used were 'best guesses' as is inevitable in such an exercise. Provisional results of the analysis show that for our particular example and given the assumptions taken, the best long-run strategy for our farmer was to 'do nothing'. This is because the costs of our selected other strategies outweighed the long-run risks of experiencing loss as a result of BPS. However, as the assumptions vary (eg. the values of probabilities) so do the resulting EMVs and also therefore the likely choice of long-run strategy. For example, for Stage 1, when the probability of the herd being exposed to BVD virus is increased from the assumed 0.011 (1.1%) to 0.02 (2%), the strategy of 'ensuring only disease free replacement stock' replaces the 'do nothing' one as the best strategy choice for our farmer over the long-run.

DISCUSSION

Limitations of Analysis

(i) The results of the analysis are obviously only as good as the values given to each of the variables. Many of these values are guestimates and are difficult to establish for different circumstances. However, sensitivity analysis helps to highlight those variables where the value is critical.

(ii) Many of the probabilities could be represented by a distribution rather than by a single value.

(iii) There is a danger that such a model over-simplifies a complex situation to the point of distorting information and giving an unrealistic picture with invalid results.

(iv) The model is essentially static (although Stage 1 and Stage 2 give some dynamic element to the model) but many values will vary over time. Ideally the progression of disease in a herd (ie. the dynamics of the disease) might be modelled and incorporated into the analysis.

Some Possible Advantages of the Analysis

(i) Relatively simple methodology, which allows a model to be 'fairly quickly' built.

(ii) The model can be seen in its entirety as a sequence of steps tracing the effects of disease and costing them according to prevailing circumstances.

(iii) The setting out of a disease problem in this way helps to (a) identify those factors of most significance and importance, (b) identify possible new strategies toward the disease, (c) think about the disease and its costs to production in a systematic way.

(iv) The model is flexible in that it can fairly easily be adapted or changed.

(v) The values of variables can very quickly be changed to (a) take account of changing circumstances (b) allow the model to be herd or farm specific (c) take account of varying estimates of disease incidence and effects (d) allow a sensitivity analysis.

CONCLUSION

The authors are aware of the simplistic nature of the methodology explored in this paper, but feel that this is more of a strength than a weakness, in that it provides a multi-disciplinary model which anyone, including farmers and producers can understand and question. The model presents information in a more usable form on which the decision maker can base a decision regarding strategies toward disease. It does not purport to make the decision (ie. that necessarily the strategy with the lowest EMV is chosen). The decision maker can see the whole range of payoffs that are likely or possible from each strategy considered, and select a strategy to optimise his own objectives. If a producer is concerned with profits over the long-run and is risk neutral, then he is likely to choose that strategy giving the lowest average EMV (lowest level of costs). However, many farmers may not be willing to risk the possibility of a disastrous outcome to their farm business and may select a strategy on a safety-first basis, accepting a higher EMV over the longer term.

It is not possible within the limited scope of this paper to more fully explore the uses of a decision tree for strategies toward BPS, nor to consider the many variations to our selected single example. Control of such a complex entity as BPS is not an easy field for decision making analysis. However, its very complexity offers an opportunity to explore and, where appropriate, to assemble and try out a modelling system. Whilst making no claims to have fully refined and tested our model, it is hoped that this investigation of the use of decision analysis and cost-benefit analysis has shown that such an approach might help in formulating policies and choosing appropriate strategies toward disease control and toward animal health problems in general.

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SOME ECONOMIC ASPECTS OF BOVINE VIRUS DIARRHOEA AT NATIONAL LEVEL

K.S. HOWE*

The Workshop to which this paper is a contribution originates from discussion of the paper by Bennett and Done (1986) at the previous meeting of this Society. Their analysis applies standard cost/benefit analysis to the appraisal of disease control strategies for bovine virus diarrhoea (BVD) at farm level. The financial effects of BVD for a single dairy herd have been investigated by Duffell, et. al. (1986) but they, in common with Roeder and Harkness (1986) among others, refer to the lack of national statistics of disease incidence. Consequently, "no estimate of its cost to the cattle industry can be made. Further exploration of cost-benefit studies are worthwhile for BVD-MD especially for selection of any control strategies". (op. cit. p39). In partial contradiction, Leitch (1986) states that "it is reckoned that in the UK, losses caused by Mucosal Disease run to a staggering £49 million. This stems from deaths, ill thrift and stillbirths". However, the basis for the estimate is not stated.

This paper attempts to put BVD into national perspective with specific reference to economic considerations. For the reasons given above, the discussion here is confined to methodological issues. The crux of the argument is that, at national level, the economic consequences of BVD are much more than the sum of its effects on individual livestock farms. Thus it is hoped that the approach may be usefully contrasted with the studies by other authors at farm level.

The paper is structured as follows. First, the relevant economic concepts are introduced, and the effects of BVD disease interpreted in that context. Second, the data requirements and their sources necessary to make an economic assessment of BVD are summarised, and two related methods for producing certain estimates are explained. The advantages and limitations of these methods are outlined at each stage. Finally, other possibilities and complications which relate to more refined approaches to the economic investigation of BVD disease are briefly introduced.

ECONOMIC CONCEPTS

A framework for studying the economics of animal disease has been presented already by the author (Howe, 1985). That earlier paper illustrated the basic concepts using a farm level example. Now it will be shown that a similar approach is relevant to the economic assessment of BVD at national level. Moreover, the same framework can be applied to any animal disease (or disease complex) which is manifested in a similar way to BVD. To begin with, however, the basic concepts are recalled and another, the first mentioned, introduced.

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The farm and the national level compared

The term 'national level' is taken in this context as synonymous with that part of the national farm sector engaged in cattle production for meat and milk. In an obvious sense the national farm sector is simply the aggregate of all individual farms. If we imagine that the legal boundaries which designate individual farms are removed, then what is left is a large-scale complex of land, labour, capital and managerial resources engaged in the process of being transformed into agricultural products.

Real production and money values

It is important to stress that the transformation process is of real resources into real products. The use of money values to express what are real resources and products is helpful, however, when it is necessary to aggregate dissimilar real resources (e.g. stockman's labour, forage area used, purchased feed, buildings accommodation) or products (e.g. milk and beef cattle for slaughter). Furthermore, the monetary residual when production costs are subtracted from sales revenue, namely profit, is the return to farmers' managerial skill. But this in turn is simply a measure of farmers' ability to acquire more real resources for the farm or goods and services for family consumption. In short, a money value expresses the possession of, or ability to acquire, diverse real resources and commodities, and that is all. Always it is the physical transformation of real resources into products which is fundamental in the present context.

Production functions and BVD

At any point in time, the resources devoted to agricultural production in total are fixed. Over time, with the possible exception of land, the other resources of farm labour, capital, and managerial enterprise, are variable. Even land is variable within the farm sector when, for example, livestock production is being expanded by the use of land transferred out of arable production. Therefore, it is possible to trace out the relationship between different levels of production and the associated quantities of variable resources used. It is this relationship which is known to economists as the 'production function'. In the present context, it is necessary to focus on the production function for cattle products. At the conceptual level it is unnecessary to distinguish between milk and meat as products. Clearly, for empirical analysis appropriate measures of cattle outputs must be defined.

Essentially, there are two production functions of importance here, (a) the relationship between cattle production and farm resources with BVD (actual), and (b) the relationship with BVD under control (target). For any given level of resources devoted to cattle production, the 'actual' function will lie below the 'target' function. The reason for this relationship between the two production functions is that the various manifestations of BVD disease have the common characteristic that all contribute to the diminished productivity of physical resources. In other words, for any given level of resources devoted to cattle (meat and milk) production, physical output is less than it might otherwise be because the disease operates as a negative input. Unlike other resource inputs (feed, the application of skilled stockmanship, and so on) disease does not contribute to production, it works actively to prevent it.

The complex aetiology of BVD-MD in cattle is considered elsewhere. However, the main ways in which the disease reduces productivity are easily identified. These are (a) the outright loss of animals from mortality, associated particularly with mucosal disease occurring typically at 6 to 24 months old, (b) abortions, still births and embryo loss, (c) reduced performance of physically weak or otherwise abnormal calves and other cattle, conveniently and collectively labelled here as 'poor-doers', of which a special case is (d) those cattle also infected with other pathogens (mixed infections) causing, for example, parainfluenza, infectious bovine rhinotracheitis and bronchopneumonia (Brownlie, 1985).

ECONOMIC ASSESSMENT

The discussion which follows mainly concerns methods which are thought to be feasible for providing information about the economic costs of BVD nationally and the potential benefits from its control. The methods, which are relatively simple, rely exclusively on the ability to give empirical substance to the conceptual framework outlined above. By virtue of their simplicity, the methods suggested should be less expensive to apply than other more refined procedures which are touched on later. Nonetheless, it is stressed that the more complicated methods may be preferred given the existence of suitable data and sufficient resources of both time and money. As is commonly the case, there is a trade-off between the degree of accuracy for an estimate and the scale of resources available to produce it. In the last resort, however, the approach followed should be determined largely by the nature of the questions to be answered.

Data requirements

Both methods outlined below need the same basic data, and it is convenient therefore to consider this aspect first. In summary, the key requirements are estimates of resource use nationally in relation to output both with, and in the absence of, BVD disease, i.e. it is necessary to learn something about the relevant production functions.

In the UK, annual statistics relating to cattle production are readily available. For example, the Ministry of Agriculture, Fisheries and Food (MAFF) publishes annual data for the production of meat and milk from the national cattle population (e.g. MAFF, 1985), and also census data for the size and age distribution of the breeding, fattening and milking herds (e.g. MAFF, 1986). Also, from the Farm Business Survey (formerly Farm Management Survey) data from college and university departments of agricultural economics (e.g. Exeter University 1986), from the Meat and Livestock Commission (e.g. MLC 1986), and from Nix (1986) and similar publications, it is possible to estimate the physical amounts and financial values of the various resources devoted to the national cattle population in any year.

Already it has been observed that data on the effects of BVD which are representative of the national herd are lacking at present. However, such data relating to BVD as are required for economic analysis include,

1. Cattle mortality at different ages because of mucosal disease.

2. Cattle mortality or slaughter necessary because of disease otherwise induced by BVD virus, at different ages.

3. Milk yield loss by infected dairy cows which eventually become immune.

4. Meat/milk yield loss of all cattle dying at various ages measured by comparison with output from the productive lifetime of unaffected animals.

5. Meat/milk yield loss of all 'poor-doers' measured by comparison with output from the productive lifetime of unaffected animals.

6. Incidence of each of the above classes of affected cattle in the total population.

Category 4 above is different from 5 only because of the occurence of death before the end of the normal expected life of cattle unaffected by BVD. In 5 a cow may complete its 'normal' breeding life, or a bullock go for slaughter as fat, but their production has been reduced in some way by the disease. The time element is important for fat cattle because slaughter weight may be identical with that of animals consistently free from BVD, but if growth rate has been checked so that affected cattle are older at slaughter, the effective output per unit time (say a year) is reduced.

It is acknowledged that acute infection in adult cattle leading to subsequent immunity (3 above) may provoke a brief and relatively minor reduction in their overall productivity. However, it is as well to make all areas of potential output loss explicit. If empirical evidence suggests that any are in practice unimportant, they can be discounted with the advantage of simplifying the calculations.

Method A

The question which Method A sets out to answer is this - by how much can total farm resource use be reduced with no change in national output if BVD is controlled? The importance of answering the question is mainly two-fold. First, the resources which potentially could be saved would then be available for other productive farm use, offering the prospect of increased farm incomes. Second, if it is farmers who gain from BVD disease control, the potential resource economies also suggest the amount that livestock farmers collectively could be expected to pay for control measures to be developed and implemented.

Such control measures, which may include test facilities for cattle and perhaps the development of efficient BVD vaccines, might emanate from public sector or private commercial research institutes, and be implemented by the state or private veterinary practitioners, or even by farmers themselves. In practice, some combination of these is likely. To the extent that farmers do not pay for disease control, such as when they benefit from publicly funded research and veterinary services, the magnitude of any net resource savings by farmers is a measure of the burden of disease control which might be assumed by taxpayers on the farmers' behalf.[1] In other words, it is a transfer from taxpayers to the benefit of farmers.

The distributional effects of any active policy, of which BVD control is an example, can get very involved. In the economic analysis of policy they are an important consideration, and so other aspects are briefly outlined later. In the present context, however, it is sufficient to note that the sum of farmers' payments and taxpayer outlays for BVD control should not exceed the value of resources saved. If outlays exceed 'repayments', it is obviously an inefficient policy towards disease control.

1. See foot of next page.

The justification for the following examples of calculations in relation to the conceptual framework can be seen from Fig. 1.

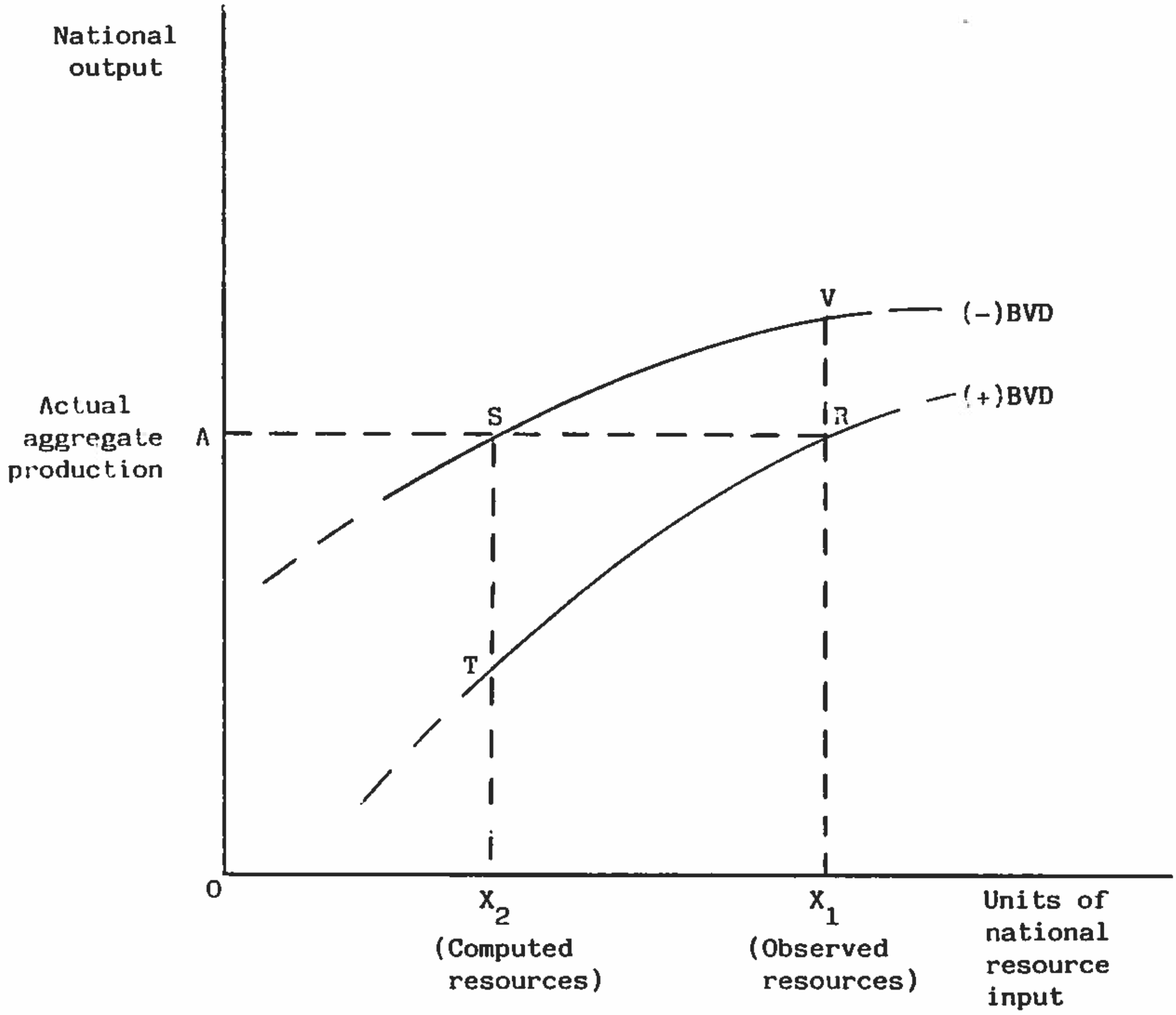

Fig. 1. Implications of Method A: production functions and the calculation of resource savings from BVD control.

For the moment, ignore the curves of the production functions and focus on point R with co-ordinates X_1 and A. Point R can be observed, because it represents the national output of cattle products (OA) from all resources devoted to cattle production (OX_1), in the present state of BVD infection in the national herd. The relevant data are obtainable from the sources listed above. Estimates relating to the national dairy herd are not difficult, but previous work by the author in a similar context suggests that calculations for the beef herd are very difficult though not impossible (Howe, 1980).

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1. i.e. Total resource savings from BVD disease control - Farmers' payments for BVD disease control = Taxpayer burden.

   This assumes that all commercial concerns (veterinary and pharmaceutical) recoup their <u>own</u> resource outlays directly or indirectly from farmers <u>but</u> resources provided by the public sector (e.g. research results from university veterinary schools) free of charge are paid for by taxpayers.

The next task is to estimate the magnitude of X_2 if output is unchanged at OA but BVD disease is controlled. In effect, the objective is to identify the location of point S. Whereas point R is a single observation on the production function with BVD, point S is an estimated location on the production function without BVD. Having observed X_1 resources and computed X_2, the magnitude of potential resource savings from BVD control is given by $(X_1 - X_2)$.

The calculations proceed from the assertion that if the productivity losses induced by BVD disease were reduced, fewer cattle would be needed to produce current levels of output. First, therefore, the number of 'live cattle equivalents' for meat and milk production lost because of BVD is computed. Implicitly, these cattle numbers represent the reduction in the national herd that would be possible if BVD was controlled because correspondingly more cattle must be kept now to compensate for lost production. The arithmetic can be illustrated in outline with the dairy herd as an example. It should be remembered that the calculations are a much simplified representation of what probably would be necessary in practice. Any 'data' are hypothetical. For beef cattle generally substitute 'weight' for 'milk' with other appropriate modifications.

Suppose that 5 per cent of the national dairy herd suffers a significant yield loss over their lifetime because of BVD disease. Then -

$$\frac{(\text{Number of dairy cattle}^{*} \times 0.05) \times \text{average total lifetime yield loss}}{\text{Average yield per annum of BVD-free cows}}$$

= Cow equivalents lost because of BVD

= Additional cows needed to compensate for lost production

*includes female cattle at all ages.

In addition, there are losses because of mortality/slaughter provoked by BVD. A familiar example can be adapted to illustrate what is implied. Suppose that the normal average lactation life of cows in BVD-free herds is 5 years, but that persistently infected herds average only 4 years. The implied replacement rates ('herd turnover') are 20 and 25 per cent p.a. respectively, i.e. BVD-infected herds need 5 per cent more surviving follower units (in-calf heifer + yearling + calf) than do unaffected herds. The example relates to dairy cows themselves, but losses of cattle at all ages influences total herd turnover, and this must be taken into account. In particular, BVD deaths of cattle being reared as replacements also requires additional 'insurance' numbers to be kept. A direct estimate for the national herd might be summarised as

$$P \times T \times S \times R = F$$

where

P = proportion of dairy herds suffering BVD-induced mortality/slaughter

T = total number of dairy herds

S = average size of persistently infected dairy herds

R = net (+) per cent difference in replacement rate of infected as against BVD-free herds

F = additional followers required because of BVD.

In short, the total effect of BVD in the national dairy herd is that, to obtain any given national level of milk production, both more milking cows and more follower units must be kept. A reduction in BVD disease would correspondingly reduce the size of the cattle population necessary to achieve any given output. By implication, resource allocation to milk (and beef) production could be reduced if BVD is controlled.

The magnitude of resource savings ($X_1 - X_2$), can be calculated in physical and financial terms by multiplying by their per unit resource requirements the numbers of additional cows and followers kept on the national farm to compensate for BVD disease losses.

Interpretation and limitations

In calculating the value of ($X_1 - X_2$) resources saved, two principles should be observed. First, the value should be computed at opportunity cost, i.e. at the value of what the resources would earn in their best-paid alternative use. Second, the resources should be expressed at present value because the gain in terms of resources saved are distributed over time. In the familiar way of cost/benefit analysis this may be 'in perpetuity' or, if it is anticipated that the efficacy of the control measures will decline over time, with a time horizon appropriately specified.

Returning to Fig. 1, from knowledge of the co-ordinates X_1 and A it has been possible to give a precise estimate for X_2 by calculating ($X_1 - X_2$). The new point with co-ordinates X_2 and A is located on a new production function, that for resource transformation into output if BVD was controlled. In both instances, however, nothing is known about the overall location of the production function, i.e. the locus of points relating different levels of output to resource use. All that is known for sure is that the function 'without BVD', labelled (-)BVD, must be above that 'with BVD', labelled (+)BVD. Also, it is expected that both curves will show diminishing returns, and thus are concave to the resources axis. This reflects the common phenomenon of diminishing technical efficiency as different resources are combined in different ratios as output increases. In the present context, for example, as the national cattle population grows more marginal land is brought into use, and so fewer cattle can be stocked per additional hectare.[1]

A factor which may affect the relative location of the two curves is the organisation of resources at any given level of resource use, X. That is because the potential productivity increase from controlling BVD may not be independent of the quantity of resources used. For example, a relatively low level of resource use (and thus output) nationally may be associated with spatially dispersed, self-contained, small individual herds. If BVD is present, subsequent control may be facilitated because essentially closed (or easily monitored) herds can be successfully protected. In contrast, a large national cattle population (high resource, high output) may imply spatial concentration of local populations, ease of contact between cattle on different farms, and concentration of cattle into large herds, leading to recurrent and widely distributed outbreaks of BVD even with conscientious preventive measures. If resource levels X_1 and X_2 in Fig. 1 are reinterpreted simply as two arbitrary levels, the foregoing implies that disease control measures at X_2 may potentially increase production from T to

1. It need not detain us here, but diminishing returns are expected even if the quality of resources is constant. In the realistic example given, the quality of land has changed as more of it is used.

S, as against X_1 with R to V, where RV < TS. The exact nature of the relationship between the (+)BVD and (-)BVD production functions can be discovered only studying the characteristics of the disease in different farming situations.

Method B

Since Method B is essentially a variant of Method A, the outline of relevant calculations can be further abbreviated. Instead of computing the magnitude of resource savings (X_1 - X_2) with output fixed at OA, alternatively it can be asked by how much output would increase if BVD was controlled for the observed level of resource use, X_1. The calculation assumes that the proportion of cattle presently dying because of BVD-MD now successfully complete their productive life. Similarly, the 'poor-doers' because of BVD are now assumed to achieve the productive potential of cattle unaffected by BVD. In other words, the losses of Method A now become translated into straight output increases.

Fig. 2 summarises the implications of this alternative approach.[1]

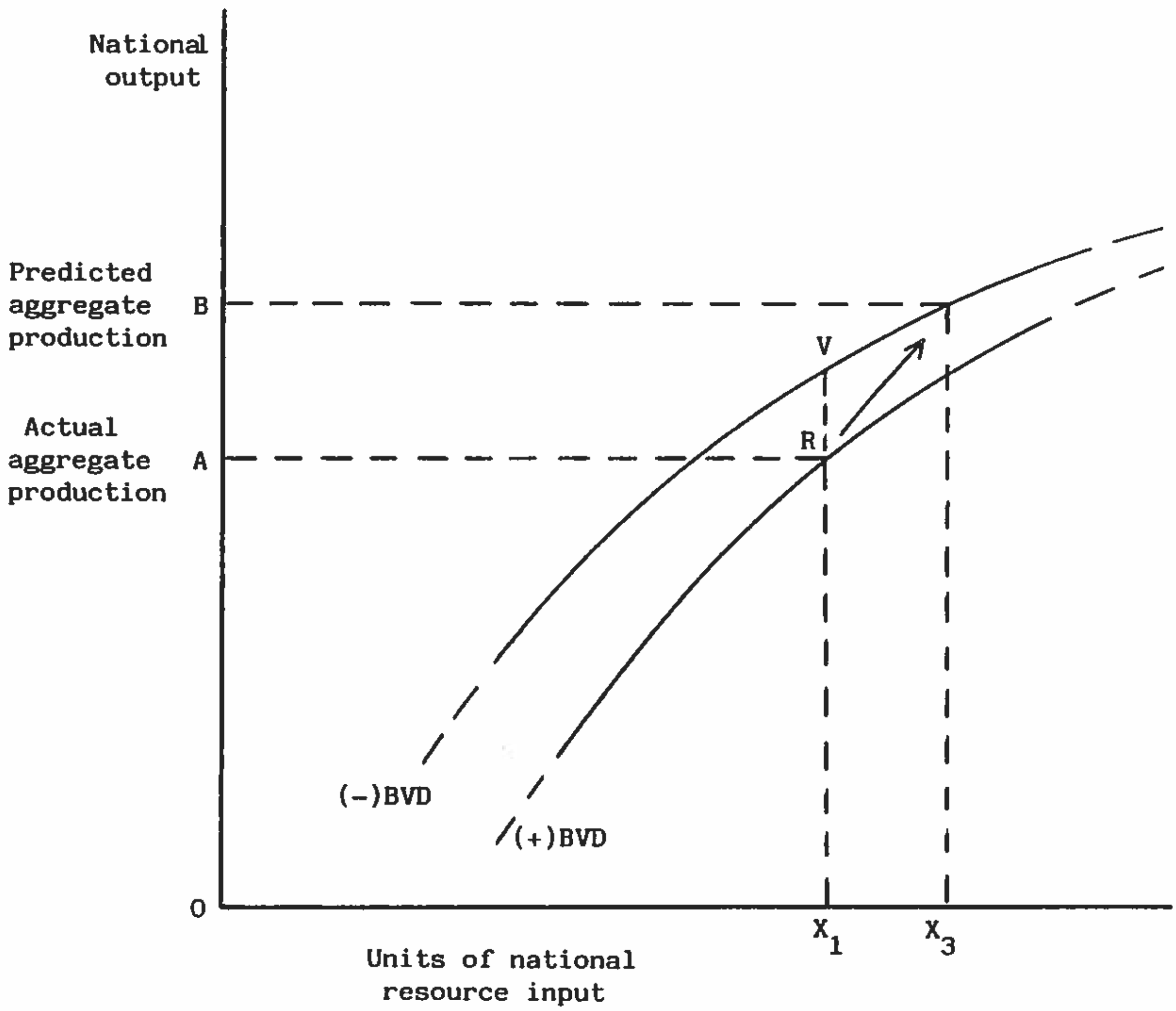

Fig. 2 Implications of Method B: production functions and the calculation of output and net resource increases from BVD control

1. The production functions are sketched slightly differently from those in Fig. 1 purely in the interests of clarifying the key arguments.

In this instance, while X_1 provides the starting level of resource use, it cannot remain constant. Most obviously, those cattle which formerly would have died through BVD-MD now live on with the disease controlled, and necessarily use extra resources. The implications for resource use by 'poor-doers' is less straightforward. Conceivably, in the absence of BVD disease no additional resources are used but the cattle are more productive. For example, they eat the same and require no significant change in labour use, but they milk better, increase in finished weight, or improve their rate of liveweight gain. This is equivalent to the vertical shift RV in Fig. 2.

Conceivably, however, there are some resource savings from previously 'poor-doers' because, for example, more feed and labour may have been required to compensate for poor food conversion efficiency and to treat ill-health. To the extent that a proportion of previously unthrifty cattle now offer scope for resource economies, these gains can partially offset the additional requirements of animals which previously would have died. Currently, the net effect of resource savings and additional requirements is a matter for speculation. Data are needed before estimates can be made. However, Fig. 2 depicts perhaps the most probable outcome, with some additional resource use raising the total level from X_1 to X_3. As a result, national production rises not to V above X_1, but to level B above X_3.

Interpretation and limitations

In summary, the situation illustrated in Fig. 2 leads to a national output increase of A to B following a resource increase from X_1 to X_3. Necessarily, these resources must be allocated from other uses and have an opportunity cost. It has to be financially remunerative for the individual farmers who together account for the increment $(X_3 - X_1)$ to commit those extra resources to cattle. In aggregate, they have another (B - A) units of output to sell which, if the additional production is to be worthwhile, must at least cover the expenditure on $(X_3 - X_1)$ additional resources. Superficially, the calculations necessary appear to be straightforward, but there are complications.

First, the additional resources may or may not include BVD control measures. To the extent that farmers themselves pay for veterinary services, vaccines, or necessary adjustments to their animal husbandry in the interests of BVD control, the increment $(X_3 - X_1)$ will include those resources. The resources which farmers do not pay for and are used in research, vaccine development, and so on, are otherwise additional. As indicated before, they must be included in any economic appraisal of BVD control which accounts for the returns to society as a whole. The same rules of accounting for the distribution of total resource outlays over time (also noted previously) will apply. Similarly, the output gains are dispersed over time. It is the net return over all resources other than BVD control measures which sets the limit to rational expenditures aimed at curbing the disease.

Second, in any competitive market, it is expected that the price per unit of output will fall as national output increases. This does not happen if an individual farmer increases production, because his individual contribution is such a small part of the total. The extent of the price reduction depends on the magnitude of the aggregate price elasticity of demand.[1] Thus the

1. Price elasticity of demand $= \frac{\text{Percentage change in quantity demanded}}{\text{Percentage change in price}}$

financial value of the additional production must allow for any fall in price per unit which, in the case of agricultural products, commonly will be substantial relative to the increase in physical production (i.e. there is a low aggregate price elasticity of demand). The retail price elasticity of demand for liquid milk in the UK currently is about -0.05, i.e. to sell another 1 per cent increase in milk output, its retail price would have to fall by 20 per cent. The corresponding measure for beef and veal is about -2, which is substantially higher than in many post-war years. In both instances, the equivalent farm gate values would be much smaller. In contrast to Method A, the alternative Method B has the computational disadvantage that price elasticities at farm level may have to be estimated if they are not otherwise available, as is usually the case.

FURTHER CONSIDERATIONS

Any increase in total quantity produced which is associated with a lower product price obviously represents a gain to consumers. The effect on producers depends on the extent to which production costs can fall relative to the reduction in gross revenue because, of course, the difference between these two variables is net income (profit). It is certain, however, that a low price elasticity of demand necessarily reduces gross revenue earned by producers when their collective output increases. The details are not considered here, but economists can attach financial values to such gains and losses if they have the data to measure the basic relationships. This is the province of welfare economics, which enables statements to be made about, for example, whether or not society as a whole is better or worse off (or neither) as a result of disease control. The gains and losses to consumers, producers, and the taxpayers who pay for public sector veterinary research, development and application, potentially can each be calculated and summed overall.

There is another important consideration. Already it has been seen that if production increases following BVD control the prices of cattle products are expected to fall.[1] It can be shown that the optimum level[2] of output (and implicitly resource use) is found from a production function by equating the ratio of price per unit output to price per unit resource input with its slope. It is reasonable to assert that in Figs. 1 and 2 the level of resources currently used, X_1, to produce output OA, is an economic optimum, i.e. with BVD present, farmers will have adjusted resources and production to those observed levels in the light of current relative prices. However, we cannot know that X_2 resources (Fig. 1) or X_3 resources (Fig. 2) correspond with optimum input/output ratios in the economic sense. Because Fig. 1 concerns the situation where output is fixed at OA, its price should remain constant. Possibly resource prices may fall when X_2 rather than X_1 are needed because (X_1 - X_2) fewer are in demand, but that depends on the value of those resources in potential alternative use. The situation in Fig. 2 is the more problematical because both output and resource prices may change in moving from output A to B with resources X_1 to X_3.

On balance, therefore, the alternative method (Fig. 2) is less preferred as a way of estimating the potential gains, and so justifiable expenditures,

1. If there exist administrative prices, such as intervention prices under the Common Agricultural Policy, it is straightforward to include them in the analysis. Such matters are not pursued here.

2. In the sense that net income to cattle producers is maximised.

in the effort to control BVD. It is stressed, however, that price variability consequent on production variations poses no insuperable problems. The crucial point which is being stressed is that, unlike when changes are made by the individual farmer, both the prices for output and resources are expected to be affected by disease control measures when they are implemented on a national scale.

Finally, and with regard to the economic benefits of research into BVD, the fact that the virus has biological and structural similarities with border disease and hog cholera (Brownlie, op. cit. p195), suggests that livestock producers of other than cattle eventually may gain from work on BVD. In principle, therefore, the wider benefits from BVD research should be taken into account when assessing the scale of resources which might be devoted to that activity.

CONCLUSIONS

This paper has outlined methods for estimating the economic impacts of BVD at national level. Emphasis has been given to those methods which appear relatively straightforward to apply. Their possible limitations have been noted, along with a brief indication of other approaches and considerations which might be feasible and illuminating given adequate data and other resources.

On a matter of detail, since in the UK the national beef and dairy herds are so closely linked, the economic investigation of the effects of BVD disease and control ought to consider the total cattle population. In illustrating Methods A and B above it was convenient to distinguish between the national beef and dairy herds. In practice, the interrelationships in the total national herd should be taken into account. However, this practical consideration in no way detracts from the basic principles which have been enunciated.

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TEACHING EPIDEMIOLOGY
AND
PREVENTIVE MEDICINE

TEACHING VETERINARY EPIDEMIOLOGY: WHAT, WHY AND HOW?

P. J. CRIPPS*

This paper describes an approach to the teaching of epidemiology at Bristol Veterinary School. It is important to remember that the amount of epidemiological teaching, and of epidemiological awareness, varies from one school to another; therefore the approach described here may not be directly applicable to other schools. However, it is believed that the problems encountered are sufficiently universal for this paper to provide a useful starting point for discussion.

WHAT SHOULD WE TEACH?

Definitions

There are many different definitions of 'epidemiology' and these can create problems (Thrusfield, 1980). Throughout this paper, epidemiology will be defined as 'The study of the determinants of disease and health in populations'. This broad heading can be divided into two sub-sections; these are i) Natural history of diseases and ii) Quantitative epidemiological methodology and thinking.

The study of the natural history of diseases calls upon many of the basic disciplines of biological and veterinary sciences (Table 1). Anything which helps to explain how a disease-causing agent behaves is of epidemiological interest, so subjects as diverse as anatomy and zoology may be important. A classical example of this sort of epidemiology is its application to microbial diseases; the behaviour of host and pathogen, and their interactions with each other and the environment all have to be considered.

The second branch of epidemiology concerns quantitative epidemiological methodology and the way of thinking that goes with this (QE). The quantitative epidemiologist should also be familiar with a large repertoire of methods and concepts. Table 2 gives some examples of the topics relevant to this and Table 3 provides some problems that the trained epidemiologist should be able to approach.

A fundamental aspect of this discipline is the fact that it is dealing with groups as the units of concern and not just with individuals. It requires a large statistical input, both in the design and in the analysis of investigations. Indeed, an appreciation of basic statistics is essential for any understanding of QE; throughout the rest of this paper it shall be considered as a component of QE.

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Table 1. Some topics relevant to the study of the natural history of diseases

Biology
Ecology
Microbiology
Parasitology
Biochemistry
Physiology
Pathology
Medicine
Surgery
Anatomy

Table 2. Some topics relevant to quantitative epidemiological methodology and thinking

'Scientific' approach
Statistics (including Biometrics)
Mathematical modelling
Survey design and Analysis
Bias and confounding
Causes and risk factors
Economics

Table 3. Some problems that a quantitative epidemiologist should be able to approach

How to design and analyse experiments
Are A and B associated? How strongly? How much difference might the possible confounders/biases make to this apparent association? Is it a causal association?
Description of the pattern of diseases in a population
Disease monitoring and surveillance
Clinical trials
Investigation of disease outbreaks
Studies of disease causation
Cost-benefit analyses
Evaluation of diagnostic tests
Critical assessment of published 'scientific' literature
Disease control programmes

It is worth a brief diversion to discuss just how much statistical training is necessary. Students must be familiar with a few techniques but it does not seem essential for the undergraduate to have an encyclopaedic knowledge of different techniques and tests. What is essential is that students should know and understand the basic concepts. These include topics such as the uses of statistics and what statistical tests are for; and they include the meaning of p-values, null hypotheses, alternative hypotheses, and confidence intervals. They also involve knowing the difference between population parameters and sample statistics. The emphasis has to be on understanding concepts rather than knowing when to apply (or misapply?) a given test.

Another important feature of QE is that, at present, it is the only discipline in the veterinary undergraduate course which deals with 'scientific methods' and concepts rather than straight facts.

Most of the components of 'natural history' epidemiology are covered to some extent in the veterinary undergraduate or pre-university curriculum. The coverage may be patchy and, at times, inadequate, but it is fair to say that by the time they graduate, most veterinary students have at least some understanding of these subjects. It is arguable that they do not need to be covered any more in an elementary epidemiology course.

In contrast, veterinary students graduate with little understanding, and indeed, an appalling ignorance of QE. In this author's experience this ignorance is not confined to new graduates; it is shared by postgraduate researchers and veterinary teachers and is coupled with a belief that QE and statistics have no relevance to them as clinicians, researchers and teachers. There is no evidence that this situation is confined to Bristol; it appears to be widespread in most of the other U.K. Veterinary Schools. The main thrust of specific epidemiological teaching therefore needs to be directed at QE.

WHY IS QUANTITATIVE EPIDEMIOLOGY IMPORTANT TO THE VETERINARIAN?

The veterinary course is already cluttered with a tremendous volume of information and it is necessary to justify the inclusion of any new material. Fortunately this is not difficult in the case of QE. Below is a selection of reasons that are used to try to demonstrate the importance of the subject to veterinary undergraduates. With one exception they are also relevant for graduates.

Firstly, it must be realised that the modern approach to farm animal production and diseases involves populations of animals as well as individuals. Clinical veterinarians still need to be able to diagnose and treat individual animals but more and more emphasis is being placed on the performance of the whole group. This situation is obvious for poultry and pigs and is becoming increasingly so for cattle, sheep and goats. This means that a veterinarian who seeks employment in the farm animal industry must be able to collect and handle group-based data, and also be able to use these data to monitor for, and diagnose, clinical or production problems. Indeed, many problems (e.g. production in pigs, fertility and mastitis in cattle) cannot adequately be diagnosed without recourse to whole-herd data.

Secondly, the importance of QE and statistics in research must be emphasised. Most veterinarians do not become researchers but for those that will, this is extremely important.

The third point, the need to be able to assess critically 'scientific' literature, is extremely relevant for all veterinarians. QE is the only undergraduate subject that gives any instruction in the approach necessary to evaluate published papers (and, indeed, claims in advertisements). Most veterinarians read some journals and many will base treatments on what they read there. Unfortunately, veterinary journals may contain papers which make claims that are not justified by the data that are supposed to support them. One of the most popular veterinary journals illustrates this point well; it provides a wealth of examples of incorrect deductions, misrepresentations, incorrectly performed and reported statistical tests, and invalid conclusions - and this is a refereed journal!

Most clinicians will perform small-scale clinical trials at one time or another, and they are likely to base their future therapies on these. (A 'clinical impression' is often the result of an informal trial.) It is important to realise the danger of misleading results from any small-scale experiment and the possible consequences of an incorrect conclusion. (e.g. a 5 percent difference in case survival between 2 treatments may not be apparent in a small trial but if 1000 cases are given the 'wrong' treatment it results, on average, in 50 unnecessary deaths.)

A fifth point is the importance of QE as an aid to interpreting the results of clinical tests; for example, patients with test results outside the 'normal' range need not be abnormal.

An understanding of QE is useful for anyone who wishes to interpret research results which are of general importance to them as responsible individuals. There are many issues, particularly in the field of human health, where the 'experts' cannot agree. Examples of these are the relative merits of different types of maternity care, and of contraceptives, and the possible association of food with health. Most people in the U.K. would consult their medical adviser on these issues but the majority of these clinicians are no more able to give properly informed advice than are veterinarians. It is suggested that any person with an interest in making informed decisions and controlling their own fate should learn some epidemiology.

A final reason for learning this subject - and one which seems to be very compelling to most veterinary students - is the fact that they have to pass an examination in it.

It is this author's opinion that some understanding of the principles of quantitative epidemiology is essential for any competent veterinarian. This is true for clinicians as well as non-clinicians. Indeed, it could be claimed that any clinician who ignores the principles of quantitative epidemiology is guilty of negligence; this may not be true legally, but it is certainly true morally.

HOW SHOULD WE TEACH EPIDEMIOLOGY?

The way that epidemiology is taught depends upon the target students and the time available. The situation will be considered firstly for undergraduates, and then in less detail for postgraduates and teachers, clinicians and academics.

Undergraduates

For undergraduates a satisfactory course would seem to be similar to that used at Edinburgh Veterinary School. This is a 27-hour course which covers both natural history and quantitative epidemiology; the subject matter can be found in Thrusfield (1986). It must be noted that this is in addition to a 40-hour course in statistics (it cannot be over-stressed that this is one of the more important disciplines used in quantitative epidemiology). Thus the total time available is nearly 70 hours; this seems to be a reasonable slice of available teaching time.

Unfortunately not all schools have appreciated the importance of the subject. At Bristol, for instance, a total of 27 hours is allocated for an entire course of statistics with computing and epidemiology. In the long term it is hoped that epidemiology will be accorded the position in the curriculum that it deserves but until then it is necessary to make the most of a very indequate time-allowance. In these circumstances it is impossible to give a comprehensive course; instead, an attempt has to be made to teach the most important topics. The way that this has been done at Bristol is as follows.

Table 4. Some topics covered in the Bristol Veterinary School Course on epidemiology, Statistics and Computing

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a) Computing: Using the 'Minitab' statistical package. Examples related to the epidemiology and statistics.

b) Statistics
The relevance of statistics
Statistics as a means of summarising data
Measures of central tendency and of dispersion
Frequency, Relative Frequency, Probability
Frequency and Probability distributions
Sampling and the properties of samples
Hypotheses and Null Hypotheses and Alternative Hypotheses
Confidence limits
Linear regression
t-tests and chi-square tests
Transformations and non-parametric tests

c) 'Epidemiology'
What epidemiology is and what it can do
The relevance of epidemiology
Looking for causes: paths and mechanisms of causation; causal and non-causal associations
Risk factors
Prevalence, Incidence, Duration
Relative risk and attributable risk
Bias and confounding
Types of Epidemiological study; cross-sectional, cohort, case-control, intervention, clinical trial
Diagnostic tests: sensitivity, specificity, predictive value
Herd and flock health schemes
Investigation of an epidemic
Critical assessment of a 'Scientific' paper

Natural history epidemiology is not taught at all during the 27-hour course. It is hoped that the students' exposure to this subject elsewhere in their training will suffice. The entire course is therefore devoted to quantitative epidemiology and methodology. This is weighted towards statistics, for the reasons that have been discussed above; two thirds of the course is basic statistics and one third is epidemiology. With this time it is obviously quite impossible to give a detailed coverage of either subject. The course therefore aims to instil an understanding of the principles and of the importance of what is being taught. Table 4 gives a flavour of the topics that are covered.

The teaching time is blocked into nine periods of three hours. The present arrangement gives approximately one hour of lecture followed by one hour of supervised non-computing practical session and one hour on the computer. This is supplemented with 'class work' which is to be done in the students' own time. In the past, printed course notes have been given to the students but the value of these is not certain.

Every effort is made to give examples that appear to the students to be relevant; the course rounds off with the critical assessment of extracts from popular veterinary scientific literature.

A major problem that this course encounters is the difficulty of motivating students to make a genuine attempt to learn and understand the subject. This may be partly a reflection of the teaching but there are other factors as well. Three of these will be mentioned here.

Firstly, the course occurs in the students' second year at a time when they are preoccupied with pre-clinical subjects such as anatomy and physiology. Other pre-clinical subjects require, on the whole, learning rather than thinking; it is very difficult to switch to a subject where concepts are more important than facts. In addition, the concentrated nature of the time available (blocks of three hours) may not encourage people to grasp concepts. Secondly, epidemiology has a mathematical component to it - and many students therefore immediately 'turn off' mentally. Thirdly, veterinary students tend to be so firm in their resolve to treat individual animals that they refuse to see the relevance of dealing with groups.

The situation might be improved by a re-schedule of the teaching of epidemiology so that it was in the clinical years of the veterinary course. Solutions must be found to these problems but difficulties such as these make no difference to the need to include quantitative epidemiology in every undergraduate curriculum.

<u>The postgraduate student</u>

The type of student referred to here is a veterinary graduate who is enrolled for a higher degree in any department of a veterinary school. These students seldom have any understanding of statistics and usually know nothing of quantitative epidemiology. Unlike undergraduates, they may need to perform statistical analyses for their research, but they often have no wish to understand statistical principles. It is proposed that all higher-degree students should be made to attend an epidemiology course, perhaps of about 30 hours. This should aim to make them understand the basic concepts so that they can pursue subjects in more depth if necessary.

Veterinary teachers

On the whole, veterinary teachers have very little understanding of what epidemiology is and why it is important. This is true of clinicians and non-clinicians alike; it is often believed that a scientific approach has no place in clinical veterinary medicine and surgery.

These people must be re-educated and persuaded to take epidemiology seriously. Unfortunately, it is impossible to force veterinary teachers to attend any lectures or courses, so it is difficult to expose them to effective indoctrination! It is not likely that many veterinary teachers could be persuaded to attend a long lecture-course. However, it might be possible to entice them to attend a few talks/seminars. These seminars would concentrate on topics such as the critical assessment of different therapies and surgical procedures, clinical trials, and the critical assessment of scientific literature. It is hoped that the target audience might be persuaded that quantitative epidemiology is for everyone. This would enable them to see that it is an essential part of any modern veterinary curriculum.

CONCLUSIONS

Most veterinarians in the U.K. have a scant understanding of epidemiology and, in particular, QE. This paper has attempted to explain why the situation must be remedied.

Veterinary schools can help by introducing epidemiology as an important part of their undergraduate curriculum, but to do this, veterinary teachers themselves need to be made aware that it is an essential subject. This means that it is not enough merely to teach students; their teachers (both clinical and non-clinical) must be educated.

It is not the function of veterinary schools to provide ready-made experts in epidemiology, or any other specialist subject, but unless veterinarians graduate with a basic understanding of epidemiology they will be unable to use their training to full effect.

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THE ROLE OF EPIDEMIOLOGY IN THE TEACHING OF PREVENTIVE VETERINARY MEDICINE

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In recent years the veterinary profession has faced changing demands for the skills and types of services it offers. Traditional methods of veterinary practice place a high degree of emphasis on those skills associated with the diagnosis and treatment of disease in individual, affected, animals. These skills are still in high demand in the fields of companion animal and equine medicine. In the field of food animal medicine, however, the tendency towards the intensification of livestock production, the concentration of livestock into large scale units, and managemental considerations in the operation of such units, has meant that the diagnosis and treatment, on an individual basis, of the animals kept under such systems has become increasingly uneconomic. The emphasis has shifted from the curative to the preventive approach, and the profession is now encountering an increasing demand from producers for planned preventive medicine packages aimed at improving the overall health and productivity of the livestock populations concerned.

This demand has faced the veterinary profession for quite a number of years. There is, however, little evidence that the necessary education has been provided at the undergraduate or postgraduate level which would enable the profession to acquire the new skills required in such an approach and permit it to fulfil this potential role in food animal practice.

EPIDEMIOLOGY AND THE PREVENTIVE APPROACH TO VETERINARY MEDICINE

The discipline of epidemiology is, by definition, concerned with the study of disease processes in populations. The basic objectives of such studies are to seek ways and means by which the frequency of occurrence of disease in such populations may be reduced. As such, epidemiology is a discipline which is inherently concerned with the preventive approach to veterinary medicine, and its teaching should form an integral part of any curriculum which is concerned with this aspect.

One of the major problems that seems to have arisen in incorporating the discipline of epidemiology into the curriculum concerns the degree of confusion that arises in the minds of many people as to what exactly constitutes the subject of epidemiology. This confusion is due, in the main, to a failure to distinguish between what one might term the theory and practice of epidemiology.

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Epidemiological theory, as it is conventionally taught, is basically concerned with introducing students to a series of epidemiological concepts; among the more important of which are the role of determinants in the disease process, the relationships between hosts and disease agents, the ways in which diseases are transmitted and the methods by which they maintain themselves in the environment and in host populations. The approach is a valid one, since it illustrates the fundamental ideas and philosophies behind the epidemiological approach and provides a basis on which appropriate interventions for the control and/or prevention of disease can be designed. It does, however, suffer from a serious constraint in that it does little to familiarise the student with the skills needed to actually practice the discipline, particularly with the ways in which epidemiological data can be generated, collated and analyzed. This involves an understanding of the methodology involved in the quantification and comparison of disease events, and the different approaches and techniques that can be adopted to study and monitor disease processes and their determinants in livestock populations. Such expertise must also be combined with a degree of statistical literacy and numeracy if the studies undertaken are to be properly designed, and the data obtained adequately analysed so that the correct inferences are drawn.

Statistics forms part of the curriculum of veterinary schools, but the subject matter covered tends to be primarily associated with conventional experimental design and analysis. Epidemiological studies are, however, undertaken in the field not in the laboratory nor under controlled conditions. The statistical techniques employed in the design and analysis of such studies differ in many important aspects from those concerned with conventional experimental methodology. Sampling theory and methods, rate estimations and comparisons, regression and time series techniques are all areas in which proficiency is required but which receive insufficient attention in the present statistical component of the undergraduate curriculum of most veterinary schools.

The attainment of the skills mentioned above are essential for the successful practice of epidemiology, but the ability to use epidemiological and statistical techniques to study disease processes in a population does not, by itself, provide a sufficient basis on which to practice preventive medicine. Any recommendations involving veterinary intervention, either in the form of the provision of veterinary inputs or changes in systems of management, must not only be sound in terms of the basic epidemiological considerations involved but must also face the managemental and economic realities of the situation if the needs of the producer are to be fully satisfied.

These considerations imply a need on the part of the veterinarian practicing preventive medicine to develop additional expertise in various areas. In particular, a thorough understanding is required of the production systems involved and the economics of their operation. Allied to this should be the ability to categorise these systems and assess their efficiency through the use of simple models based on appropriate production indicators. Methodologies for modelling production systems and for defining the production indicators used in such models are well advanced, but the generation of the latter depends on accurate and persistent record keeping. Familiarity with modern production recording methods is thus an essential prerequisite for any veterinarian interested in this area.

The use of such models, combined with appropriate epidemiological data, can indicate potential areas for veterinary intervention. Before such interventions can be recommended, however, the veterinarian must be able to assure the client that the cost of the interventions proposed are more than compensated for by the benefits in increased productivity that are likely to arise in the livestock population concerned as a result of their introduction, and that the approach recommended is more cost-effective than various possible alternatives. This implies the need for the veterinarian to become familiar with certain economic techniques, particularly those concerned with cost-effectiveness calculations.

While the theoretical basis to many of the techniques discussed above is relatively simple, their application in the past has been constrained by the lengthy and laborious procedures that had to be gone through if they were applied using manual methods. This meant that their adoption was constrained on practical grounds. The advent of microcomputerised information processing technology has radically altered this situation. An ever increasing range of cheap and increasingly easy to use software and hardware has meant that most of the recording and all the data processing and analysis necessary can now be performed quickly, easily, and at relatively low cost. It is particularly disappointing that the profession as a whole has been so slow in appreciating and exploiting the potential of these new developments and that so little is done in veterinary colleges to alert students to this potential.

THE POSSIBILITIES FOR TRAINING IN EPIDEMIOLOGY AND ASSOCIATED TECHNIQUES

While it is a relatively easy matter to postulate the range of skills necessary to practice preventive veterinary medicine, it is much more difficult to see how training opportunities in those skills can be made readily available to the profession. At the undergraduate level, the already overcrowded curriculum, and the fact that the skills mentioned are really only of practical significance in a specialist area of veterinary medicine, means that it is unlikely that large amounts of time can be devoted to their acquisition.

Given the restrictions imposed by time-tabling, the main emphasis at the undergraduate level should be placed on creating an awareness in students of the availability and potentials of the techniques and skills discussed. It is to be stressed that the aim should not be to impart complete expertise but to interest and stimulate. Much would depend on how the various topics are taught and presented. Since much of the subject matter might seem to be of doubtful relevance to the practice of veterinary medicine as it is perceived through the eyes of an undergraduate, emphasis needs to be placed on illustrating the potentials with real examples from the field of veterinary medicine in order to capture the imagination of the majority of students, even if non-veterinarians are involved in presentations.

If such an approach is adapted, then a lot could be achieved without imposing severe demands on existing timetables, particularly if some reorientation of subject matter in topics already taught is undertaken.

It is at the postgraduate level that more detailed and comprehensive training should be implemented. While the idea of a formally taught course at the MSc level is attractive, it does have certain disadvantages in that high fee rates, difficulties in obtaining sponsorship, and the length of time necessary to complete such a course may discourage many potential participants, particularly those making a career in general practice.

Various alternatives suggest themselves. An externalised MSc course along the lines of those run by the Open University, with emphasis on home study and making use of modern telecommunications, particularly in computing and related fields, combined with short intensive training courses, could be an attractive option to certain individuals.

Alternatively, or in conjunction with the above, a range of modular courses, varying in duration from two days to two weeks, on a whole series of topics which are separate entities in themselves but which also combine into a comprehensive and coordinated whole, could be developed. This would permit various degrees of specialization on the part of students undertaking such studies. For example, veterinary research workers, with initial postgraduate training in virology, bacteriology etc., might wish to attend only those modules on more advanced analytical epidemiological techniques in order to broaden or fulfil their research programmes. Veterinarians engaged in general practice might wish to concentrate on those modules dealing more with preventive medicine. In all cases, the experience and problems of the participants could be used for at least part of the teaching to aid comprehension and maintain interest and motivation. Such an approach would require suitable sponsorship and an institution willing to undertake the necessary organization.

Whatever the method, there can be no doubt that the provision of such training opportunities, combined with an increased flexibility of approach on the part of the profession to the provision of its services to the livestock sector, is long overdue. Unless the opportunities available are fully grasped and exploited, we shall continue to provide services which are becoming increasingly obsolete and which no longer cater to the needs of the livestock sector. The dangers of such a situation to the future well-being of the profession are inherently obvious and are ignored at its peril.

TEACHING EPIDEMIOLOGY AND PREVENTIVE MEDICINE: CAN IT BE FUN? - THE LIVERPOOL ATTEMPT!

M. J. CLARKSON*

A perusal of old timetables for 4th and 5th year undergraduate veterinary students at Liverpool Veterinary Faculty indicates that statistics, epidemiology and preventive medicine have all been allocated named space for at least some of the past 20 years! This observation shows that it is not entirely true to say that the importance of these subjects has not been appreciated by veterinary teachers, though it does not mean, of course, that the skills required to practise these disciplines were actually communicated to the thousand or so graduates who have joined the veterinary profession with Liverpool degrees over those years. The current undergraduate timetables, however, show that none of these three subjects is given named space!

My personal involvement over the same period indicates that I have had some responsibility for each of these subjects for at least part of the past 20 years, which means that I can speak personally of the attempts which have been made and, incidentally, also makes it likely that I shall be somewhat defensive when it is suggested that the profession is not being adequately trained for the opportunities available in and the services being demanded by, the livestock sector! After all, no-one likes to think that they have taught 1,000 bright students for 20 years without at least a few of them having benefited!

In this paper, I would like to examine the attempts at teaching statistics, epidemiology and preventive medicine with which I have been associated, try to assess their success and draw attention to problems which arose. I would then like to look at the reasons which may have affected their success and, finally, indicate the methods which we are currently using to attempt to teach these subjects.

TEACHING STATISTICS

When I was a student in the 1950's, we were given a course of 10 weekly lectures on statistics in the 2nd year by a learned member of the Department of Statistics and Numerical Analysis. The student survival rate fell in an exponential manner with a half-life of approximately 7 days! Of the 30 students who started the course, about 2 were present at the last lecture. I am sure that the teachers involved were competent, enthusiastic and put a reasonable amount of time into the preparation and delivery of their lectures.

No-one could pretend that they were successful - and the classes certainly were not 'fun', for students nor, probably, for the staff involved. There was no 'statistics' section in any examination, the

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course did not appear to be relevant, the students went to a non-veterinary building to receive the course and the majority of veterinary teachers did not appear to use the techniques which were described.

In the early 1970's, although I was responsible for teaching parasitology, I rashly volunteered to organise and teach a course of 9 x 3 hour classes on statistics for 2nd year veterinary students. A Faculty grant of £2,500 enabled me to purchase 20 primitive electronic calculators, which would only carry out the four basic arithmetical procedures! An attempt was made to make the classes enjoyable and, in those days, the calculators were a great attraction! No lengthy formal lectures were given but a problem was set and the students, working in pairs, were encouraged to solve it. Ten-minute discussions or mini-lectures, were slotted in at appropriate places during the 3 hour period. The subjects covered included variability, sampling, frequency distributions, means, standard deviation and error, significance tests, 'd' and 't' tests, Chi square, correlation, regression and simple experimental design.

Again, there was no specific examination in 'statistics' although the possibility of this was discussed. On the one hand, it was felt that it would be unreasonable to allow a student to fail a degree examination over as 'unimportant' a subject as statistics, whereas on the other, it was felt that statistics was a core subject and must be examined to ensure that it was taken seriously. There is no doubt that examination status influences the attention (and attendance!) which is given to a subject by busy undergraduates. This is particularly true when the students are studying other subjects at the same time which are examined and which must be passed in order to continue with the course.

The only measure of success which we had was the attendance at the classes and the rather subjective degree of enjoyment which was felt by the participants. Attendance, which started at 40, fell to 20-24 by the 3rd class and then continued at this number for the rest of the course. At least it was not a single exponential! Those who stayed, enjoyed it - and so did I!

A similar course, with almost identical attendance pattern, was held for 5 years but was discontinued in 1975 and no formal statistics course is taught at present. I am of the view that this course had some rather limited success, - perhaps because it was, to some extent, and to some students, 'fun'.

It was then decided that statistics should be taught as a 'tool' of other disciplines and has now been incorporated into other subject courses, mainly into physiology and biochemistry. In each of these subjects, the teaching is made enjoyable by the use of statistical techniques to interpret the results of experiments which the students have carried out themselves. Students analyse their results by hand and then by computer. An understanding of statistical techniques is assumed in teaching in genetics, animal breeding and clinical science. This statistical teaching seems to be entirely acceptable and enjoyable to students but the criticism has been made that no-one on the staff knows precisely what has been taught as a whole.

TEACHING EPIDEMIOLOGY

A course of 9 one hour lectures in the 4th year of the course, dealing with the principles of epidemiology has been held for over 10 years. It has sometimes been given by one lecturer, more frequently by two and after a major overhaul in 1984, was given by six different lecturers. I gave 4 of the lectures and attended the others in order to attempt to make sure that the major topics were covered without undue repetition. The table below indicates the content of the course.

Table. Epidemiology Lecture Course

Subject	Examples	Lecturer
1. Epidemiology as veterinary detective work Measurement of quantity of disease Morbidity/Mortality rates Epidemic curves	Salmonellosis epidemic Foot and mouth	A
2. Epidemiological 'triad' Host, agent, environment Multifactorial disease	Lameness in dairy cattle	B
3. Maintenance of infection Host, agent, environment	Cat respiratory viruses	C
4. Diseases of unknown aetiology Surveys, case control, case cohort Tests of association	Feline urolithiasis syndrome Feline dysautonomia	D
5. Methods of obtaining/recording/ processing data	Farm Animal Recording System	E
6. Surveys of disease incidence and epidemiological diagnosis	Laying chicken flocks	F
7. Models 1: value in epidemiology and control	Ovine abortion (Toxoplasma)	A
8. Models 2: value in epidemiology and control Disease forecasting	Parasitic gastroenteritis Ticks, Fluke	A
9. The economics of disease and its control Cost benefit analysis Alternative strategies National control schemes	Bovine mastitis Brucellosis	A

The idea was that epidemiological principles would be taught by veterinary surgeons who had used a particular principle or technique in a real investigation. It was hoped that this would convey the idea of relevance to the subject, which had been a criticism of the previous course. Another feature of the course was that we attempted to give the students something to do, - plot epidemic curves, calculate rates, postulate and test theories of causation.

There is little doubt that the lecturers were all enthusiastic and are at the very least, 'reasonable' teachers but, as you will see later, after running the course for two years, even I could not pretend that it was really successful.

Attendance records were good but the subject formed a major part of one terminal examination which, although it did not count towards a degree examination, provided a source of embarrassment to any individual student who did very badly. Some of the epidemiological principles which were taught could appear as short questions in the final degree examination and it was expected that students would be able to use the techniques in preventive medicine projects later in the course. These factors probably influenced the attendance.

The course was also assessed by a different method. For several years, clinical teaching has been assessed at Liverpool by a standard student questionnaire. This allows students (anonymously) to give a numerical score to a particular course and also to provide comments, if they wish. The assessment is made at the end of the particular year of study which obviously only gives an 'immediate' reaction. It is possible that the assessment would change after the student had graduated and been in practice for a few years. The numerical score is rather like a sheep condition score - 1 'poor', 5 'outstandingly good', with 3 'average'. The score for 'epidemiology' was 2.2 with a standard deviation of 0.9!

When I came to read the comments I was touched by the first one which said 'Great fun but we didn't seem to learn a lot'! The majority were less complimentary and again, indicated that the students were apparently unable to see the relevance of the course, despite the fact that we had used examples that were genuine and interesting to us as teachers.

A comparison can be made with the assessment of cattle rectal technique for pregnancy diagnosis and subfertility, taught by an on-farm visit by a group of 6 students, who did one half day each term, the day after the epidemiology course - and incidentally, also taken by me. The score was 4.19 (SD 0.65) and the comments were glowing! The difference between these two scores was highly statistically significant.

This led me to question the reasons for the apparent antipathy to epidemiology and the obvious enjoyment of rectal technique. I first of all thought perhaps our students had a horror of mathematical treatment of data since some mathematics was involved in each lecture on epidemiology. I, therefore, carried out an analysis of the entry qualifications of our students over the past 6 years in order to attempt to assess their mathematical background. I had 'A' level grades for 307 students and 141 (46%) had mathematics as one of their subjects. Sixty-eight had an A grade in mathematics and a further 51 a B grade! I decided that this was unlikely to be the major reason for their lack of appreciation of the subject.

I had to return to the question of apparent relevance to the students and to their motivation. The 4th year of the course is the first major introduction to clinical work, both in University and in vacations by 'seeing practice'. The students have been waiting for this exciting work for 3 years and were now involved in clinics involving medicine and surgery. This meant that the majority of the teaching which they were receiving was clearly relevant to veterinary practice and was thus enjoyable. The greater part of their extra-mural tuition 'seeing practice' would concern individual clinical cases and the students would again perceive the immediate relevance of most of their clinical teaching. The attitude of veterinary surgeons in practice would affect their view of the relevance of any subject. Rectal technique was such an example. In the midst of this came the epidemiology course which was endurable but certainly not enjoyable.

After two years, the same decision was made as had been made earlier over the statistics course, i.e., an attempt is being made to incorporate the epidemiological principles into the course on clinical diseases. For example, the differences between prevalence and incidence rates can be made in lectures and practical teaching on the different types of mastitis, epidemic curves into infectious diseases such as salmonellosis and foot and mouth disease and modelling into parasitic conditions. The same teachers who had combined in the epidemiology course now transferred their teaching to the particular part of the course in which the disease condition was described. Ideally, the students should absorb an epidemiological approach or way of thinking without even realising it.

The method can be criticised in that the subject is not dealt with systematically and is much more difficult to co-ordinate and ensure that the important concepts are taught - and learnt. Since the method has only been used this year it is not possible to attempt to assess its effectiveness.

TEACHING PREVENTIVE MEDICINE

In 1976, when I was appointed Professor and Head of the Department of Veterinary Preventive Medicine, a lecture course, combined with farm visits, was given on the subject of preventive medicine and appeared as such on the timetable. In 1983, the Department of Veterinary Preventive Medicine disappeared in a 'rationalisation' exercise, combining with the Department of Veterinary Clinical Studies to form a single clinical department, Veterinary Clinical Science - and the title of my own chair has recently been changed from Veterinary Preventive Medicine to Farm Animal Medicine! This does not sound too good for 'Preventive Medicine'!

However, teaching on preventive medicine has greatly expanded and pervades the whole of the theoretical and practical teaching of the subjects involved in farm animal medicine but again, no mention is made of 'preventive medicine' as a subject on the 1986/7 timetable. It would be impossible to separate the 'clinical' and 'preventive' aspects of each disease as currently taught at Liverpool and since our teaching in Farm Animal Medicine is on a species basis - cattle, sheep, pig and poultry medicine courses, it is natural to deal with all aspects of each disease and at the end of the course, combine preventive measures into health programmes for each species.

The practical teaching of preventive medicine has been modified almost every year but a general pattern is now discernible which is modified slightly according to the species. The aim has been to stimulate and develop the interest of 5th year students in solving real problems and is always carried out on farms, either as part of the Farm Practice of the Department or in collaboration with nearby veterinary surgeons in general practice. Typically, 6 students accompanied by one member of staff spend one week on a farm project in which they seek to obtain and analyse information about production and disease incidence, collect and analyse samples, examine clinical cases and healthy individuals and the group, discuss the farm with the farmer and try to understand him, his problems and aims.

Each student is allocated a specialism and is a member of an investigating team co-ordinated by one student, who is the 'veterinary surgeon'. During the sheep project, for example, the 5 specialists are nutritionalist, farmer, parasitologist, economist and gynaecologist/paediatrician. We have found that it is preferable to use a different farm for each group of students (we need 8) and it is possible to go to a strange farm and complete a useful piece of work within the week.

During the week, the group meet and formulate their ideas about the main problems of the farm and the possible methods whereby they may be resolved and a typed report is produced by the 'vet', from material submitted by each specialist. The farm is revisited at the end of the week and the 'vet' presents and discusses the report, aided once again, by the team.

Every 5th year student is involved as one of a group of six in projects of a week each, on bovine mastitis, dairy herd health, sheep health and intensive livestock (pig and poultry health).

There is no doubt that this type of teaching <u>is</u> fun, for most of the students and for the staff involved. This <u>subjective</u> enjoyment is supported by attendance records (virtually 100%) and by student questionnaire scores (3.9 - 4.4) and comments e.g. 'Makes you <u>think</u>, which is always good for the brain', 'Excellent, I learnt masses that week', 'A very enjoyable worthwhile week'!

It is a very intensive demanding method of teaching and requires considerable staff involvement and enthusiasm. It makes demands on a wide range of disciplines taught in the earlier part of the course and stimulates enquiry in students and staff and forces us all to think epidemiologically against an economic background. In two of the project groups, it allows students to use computers.

It is possible that an elective system could be devised which would allow this type of teaching to be available with less total staff involvement. Thus, if each student carried out one dairy cattle project (instead of two at present) and either sheep or pigs/poultry (instead of both), only half as much staff time would be involved.

Furthermore, it can be assessed to some extent by the actions and comments of employing veterinary surgeons of new graduates which are (almost) universally complimentary. For example, a few years ago, I was contacted by one of our very recent graduates asking for advice on the conduct of an evening's meeting for the practice sheep clients. This individual had asked his principal why none of their 100 or so sheep clients used the practice for advisory work. His principal replied that if he knew how to produce and market health programmes for sheep farmers, he had his blessing to call a meeting. Twenty or so turned up by invitation and some of them availed themselves of the new service which the practice was able to provide for this branch of the livestock sector.

CONCLUSIONS

I have tried to indicate that teaching of the subjects of statistics, epidemiology and preventive medicine to veterinary undergraduates poses similar problems - largely of apparent relevance to the undergraduate student. One possible approach is to incorporate these subjects into areas of the courses where the relevance is apparent and, particularly, to attempt to make them enjoyable or 'fun' for students and staff by relating them to practical problem solving exercises, preferably of a genuine nature on real farms.

I do not think that we at Liverpool have succeeded in every respect and expect that we shall continue to modify our teaching so that we might produce the epidemiological outlook which we all believe to be important in so many aspects of veterinary work.

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AIMS AND OBJECTIVES OF AN EPIDEMIOLOGY COURSE FOR POSTGRADUATE VETERINARIANS (MSc, ANIMAL HEALTH, LONDON)

A. J. MADEL*

The Royal Veterinary College offers a postgraduate course in Animal Health which leads to the degree of MSc from the University of London. The course is held in the Department of Animal Health and Production and provides an advanced education in animal production and animal health. It is primarily concerned with production and health in four farm animal species; cattle, sheep, pigs and poultry. The course, which lasts 12 months, has three sections:

(1) three terms of lectures, seminars and practicals,

(2) the Easter vacation is spent gaining practical experience, often in diagnostic laboratories,

(3) the summer vacation in which students undertake a three month practical project in a subject which they have chosen in consultation with their supervisor.

The examination consists of written papers, the assessment of the practical project report and an oral examination.

The course is open to any registered veterinarian who has obtained an academic qualification approved by the University of London. In the past, all course entrants have had some experience of working in the field and this has varied from just one year to 15 years. Students with several years practical experience contribute to, and gain more from, the course than those with little experience, although the older students may find the discipline and process of learning from an intensive course hard.

The numbers attending the course each year have varied between 5 and 13. At least 50% of each year's intake have been from overseas and since the course started 45 countries have been represented. The first course began in 1965 and was organised by Professor J A Laing and Mr A L C Thorne. Those who successfully completed the academic year were awarded the Diploma in Animal Health. In 1967, Professor J E T Jones took over the running and organisation of Animal Health and remained with the course until 1984. Under his direction the course became well established and gained a high reputation in Britain and internationally.

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In 1977 the course of study was extended to one calendar year and successful candidates were awarded the degree of MSc. The principal change was the introduction of a practical project. Previously, students had been required to submit a dissertation (review of the literature) on a subject of their own choice. The practical project now allows students to gain experience in the planning, execution and writing up of research work, albeit of a modest nature; several students have taken up research as a career and have obtained the PhD degree at this or other universities.

Dr A J Wilsmore became the director of the course in 1984. Since the time the postgraduate course was established in 1967 and the end of the 1985/86 academic year, 177 veterinarians have completed the course; 96 gained the Diploma and since its change in status from 1978, 81 gained the MSc degree.

THE SYLLABUS

There are four sections to the syllabus of the Animal Health course

(1) Animal Production,

(2) Basic veterinary sciences,

(3) The epidemiology, pathogenesis, diagnosis and control of economically important diseases of farm animals,

(4) Organisation and administration of veterinary services, nationally and internationally.

The epidemiology course is part of the basic veterinary sciences section and is taught early in the first term. The statistics course (not taught by the author) is taught in the same term.

The following topics are discussed in the epidemiology course:

- the epidemiologist's attitude to disease,
- the host, the infectious agent and the environment,
- the frequency of disease,
- factors affecting disease; forming an hypothesis,
- John Snow on cholera,
- descriptive, analytical and experimental epidemiology,
- problems of diagnosis,
- eradication, elimination or control?
- the uses of epidemiology.

These topics are discusssed in 10 to 11 hours of classroom time using a variety of teaching methods.

AIMS

Definitions of aims, and distinctions between aims and objectives in the literature are inconsistent. Aims are general or abstract statements about the long-term purposes of a course, the long-term effects the teacher hopes it will have upon a student. Objectives specify what a student should be able to achieve having attended the course; objectives identify expected changes of behaviour consequent on learning (Rowntree, 1982). When teachers discuss courses in veterinary science, they are usually referring to the syllabus, that is, the list of topics they intend to cover. Sometimes there is little thought on whether the students can also cover the same ground, let alone learn anything from it. In the Proceedings of a previous seminar on the teaching of veterinary epidemiology (Proceedings, 1978), there are frequent references to the already crowded veterinary undergraduate curriculum. The author is not aware of significant reductions of the curriculum in most veterinary schools since 1978.

British veterinary schools are not unique in providing an undergraduate course which is overloaded with formal teaching. Most students on the Animal Health course have been subjected to excessive amounts of formal and didactic teaching (the university lecture). This form of teaching results in a majority of students adopting what Perry (quoted by Warren Piper, 1984) refers to as 'position one' on a scheme which illustrates the development of learning strategies in students: "authorities know, and if we work hard, read every word, and learn Right Answers all will be well". The table below illustrates Perry's nine positions of cognitive and ethical development.

Table 1. Scheme of cognitive and ethical development

Position 1	Authorities know, and if we work hard, read every word, and learn Right Answers, all will be well.
Transition	But what about those Others I hear about? And different opinions? And Uncertainties? Some of our own Authorities disagree with each other or don't seem to know, and some give us problems instead of Answers.
Position 2	True Authorities must be Right, the others are frauds. We remain Right. Others must be different and Wrong. Good Authorities give us problems so we can learn to find the Right Answer by our own independent thought.
Transition	But even Good Authorities admit they don't know all the answers yet!
Position 3	Then some uncertainties and different opinions are real and legitimate temporarily, even for Authorities. They're working on them to get to the Truth.
Transition	But there are so many things they don't know the Answers to! And they won't for a long time.

/cont'd

cont'd/

Position 4a	Where Authorities don't know the Right Answers, everyone has a right to his own opinion; no one is wrong!
Transition	But some of my friends ask me to support my opinions with facts and reasons.
(and/or) Transition	Then what right have They to grade us? About what?
Position 4b	In certain courses Authorities are not asking for the Right Answer: They want us to think about things in a certain way, supporting opinion with data. That's what they grade us on.
Transition	But this 'way' seems to work in most courses, and even outside them.
Position 5	Then all thinking must be like this, even for Them, Everything is relative but equally valid. You have to understand how each context works. Theories are not Truth but metaphors to interpret data with. You have to think about your thinking.
Transition	But if everything is relative, am I relative too? How can I know I'm making the Right Choice?
Position 6	I see I'm going to make my own decisions in an uncertain world with no one to tell me I'm Right.
Transition	I'm lost if I don't. When I decide on my career (or marriage or values) everything will straighten out.
Position 7	Well, I've made my first Commitment!
Transition	Why didn't that settle everything?
Position 8	I've made several commitments. I've got to balance them - how many, how deep? How certain, how tentative?
Transition	Things are getting contradictory. I can't make logical sense out of life's dilemmas.
Position 9	This is how life will be. I must be wholehearted while tentative, fight for my values yet respect others, believe my deepest values right yet be ready to learn. I see that I shall be retracing this whole journey over and over - but, I hope, more wisely.

The primary aim of the epidemiology course is to move students away from a dependent learning style to a more independent and confident approach: a move to position 4b seems to be a reasonable target. If students appreciate that the epidemiology course requires them to adopt a questioning attitude to their learning, this should help them to enjoy the whole of their year on the Animal Health course.

Several authors have discussed the different types of learning which occur in higher education and have produced their own classifications. Beard and Hartley (1984) discuss learning under three headings; knowledge, skills and attitude. The learning of attitudes is a complex subject and attempts to change peoples' attitudes are fraught with difficulties (and dangers!). Nonetheless, the second aim of the epidemiology course is to change an attitude.

Undergraduate veterinary courses prepare students for a registerable degree and teachers are rightly concerned that newly qualified graduates have an acceptable level of competence to deal with the sick animals which members of the general public will present to them. The undergraduate course, particularly in its latter two years, is therefore strongly concerned with teaching the diagnosis and treatment of individual, sick animals. There has been a growing realisation of the importance of population medicine in recent years, but the author contends that the majority of students still graduate with an attitude to veterinary science which is primarily that of dealing with the individual animal. The second aim of the epidemiology course is to change peoples' attitude to one of thinking of veterinary science in a <u>population</u> of animals.

OBJECTIVES

Objectives state what a student should be able to do as a result of following a particular course. The care and precision which is employed in writing objectives should match that which is used when writing examination questions. Writing objectives is a difficult task. The author's experience of university teaching has, until fairly recently, tended to reinforce the belief that the prime task was to 'cover the ground'. Many colleagues regard objectives as too mechanistic or narrow and see them as lowering the educational process to one of training. If objectives are perceived in this manner, their proper form needs explaining and their advantages need emphasizing. Objectives let staff and students know the intended outcomes of teaching; they specify what students should be able to do as a result of their learning. They help the teacher decide the content and sequence of subjects to be taught; they help in deciding what is the most appropriate teaching method for a specific part of the course. Finally, they give clear standards on which to make assessments and evaluations.

Engle (1980), in advocating the value of objectives in medical education, gives a perfect analogy to research. "No application for a research grant would deserve serious consideration unless it defined the problem to be investigated and demonstrated the logic and rigour of the method to be used. Does the education of medical undergraduates deserve any less serious attention to planning, implementation, assessment and evaluation?"

Two examples of objectives from the author's own epidemiology course have been chosen to illustrate the general points made in the preceding paragraphs.

One of the aims of the course is to move students away from thinking of disease in terms of the individual sick animal. To this end, an hour's session is devoted to discussing the different ways in which clinicians, pathologists and epidemiologists consider disease. A brief account of a clinician's approach to a case is given under the following headings:

how a history is obtained,

the method of examination,

the form in which a diagnosis is given (including the degree of confidence expressed),

the action which is taken and the method by which the owner is kept informed of the whole process,

the clinician's concept of the cause of disease,

the principal framework which the clinician uses to advance clinical expertise (ie. the differences between similar cases).

Students are also asked to state what they consider to be the hallmark of a successful clinician. They are then asked to write down the sequence which a pathologist and epidemiologist might use when approaching an incident of disease. They are then asked to form into two teams and to pool their ideas for presentation to the class at the end of the session. The objectives for this session are shown below:

<u>The epidemiologist's attitude to disease - objectives</u>

At the end of this part of the course you should be able -

1) to explain the various steps which clinicians, pathologists and epidemiologists take when confronted with a case,

2) to distinguish the different concepts of disease which these three groups of people are likely to have,

3) to state the principal framework in which a clinician, pathologist and epidemiologist thinks about disease,

4) to comment constructively on these objectives.

A majority of students on the Animal Health course are government veterinarians who are likely to be involved in designing and implementing health schemes in populations of farm animals. There are many aspects to the problems of diagnosis, not all of them scientific, which students need to identify and relate to their own circumstances of work. The objectives for this part of the course are shown below:

Problems of diagnosis - objectives

At the end of this part of the course you should be able -

1) to distinguish between the issues which arise when the problems of diagnosis are placed in three categories; namely - why diagnose? what to diagnose? and how to diagnose?

2) to explain why two diagnostic procedures employing exactly the same diagnostic method on the same animal may produce dissimilar results.

3) to define and distinguish the terms 'sensitivity' and 'specificity'.

4) to assess the biological, social and economic consequences of the sensitivity and specificity of the diagnostic test used in a disease control or a disease eradication programme.

5) to comment constructively on these objectives.

The author has found that students often have difficulty in distinguishing the difference between the sensitivity and specificity of a test and, similarly, in identifying the veterinary, social and economic consequences of wrong positive and wrong negative test results. A simple (and simplistic) example of the results a test might produce is demonstrated using models of infected and clean animals. The author regards the understanding of this aspect of the course as paramount and to this end, students are asked to write an answer to the following question some weeks after the end of the course:

> 'Diagnostic tests are characterised by their sensitivity and specificity;these characteristics identify the magnitude of the two types of incorrect results, wrong positive and wrong negative results.
>
> What characteristics should a good screening test have? In what circumstances would you use a screening test? Choose examples of diseases to illustrate your answer and explain the steps you might take to minimise the effect of any incorrect results obtained during screening tests.'

CONCLUSION

Epidemiology "is a method of thinking, an attitude towards disease in the population; a technique for exploring the causes and aiming at the prevention of disease from whatever cause" (Wilson, 1974).

The epidemiology course, which is a very simple introduction to the subject, and the statistics course serve to initiate a radically different approach to veterinary science from the one most Animal Health students probably adopted as a result of their undergraduate training and initial experience as a practising veterinarian: both courses are given in the first term. This epidemiological approach is emphasized throughout the Animal Health course by teachers who discuss specific diseases. In the third term two days are devoted to disease modelling; students use computers to design and evaluate a disease control programme.

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PORCINE EPIDEMIOLOGY AND PREVENTIVE MEDICINE

EPIDEMIOLOGY OF SWINE DYSENTERY

R.J. LYSONS*

This paper is primarily concerned with an examination of the epidemiology of swine dysentery although some aspects of treatment and control are also covered. A "textbook" description of the disease as a whole is given by Harris and Glock (1986).

AETIOLOGY

Swine dysentery is initiated by the anaerobic spirochaete *Treponema hyodysenteriae*. Experimental infections using cultures of this organism in conventional pigs produce a disease identical with that seen in the field (Taylor & Alexander, 1971; Harris et al., 1972). In gnotobiotic pigs, however, infection with *T. hyodysenteriae* causes a much less severe disease. This suggests that other organisms contribute to the pathogenic process. Bacteria which may play this role have been suggested (Lysons et al., 1978; Whipp et al., 1980), but the identity of the "other agents" remains largely unresolved. Pigs from many different sources appear to be equally susceptible to challenge with *T. hyodysenteriae*. This suggests that the "other agents" are ubiquitous. Epidemiologically, it is simpler to regard the disease as being caused by *T. hyodysenteriae*. This assumption appears to be justified because the presence of disease correlates with large numbers of *T. hyodysenteriae* in the large intestine and because pathogenic *T. hyodysenteriae* have not been found in herds which are free of swine dysentery.

THE DISEASE

Swine dysentery is a muco-haemorrhagic diarrhoeal disease which is present in all major pig rearing countries (Roncalli & Leaning, 1976). It affects only the pig, and lesions are confined to the caecum and colon. It is most commonly seen in growing and fattening pigs, and in marked contrast to other enteric diseases, rarely occurs before 5-8 weeks of age. In intensive indoor units, breeding stock only occasionally contract the disease, presumably because they are kept in relatively clean conditions, but it is much more commonly seen in sows kept outdoors which can be exposed to a greater challenge.

Another characteristic of the disease is the long incubation period between infection and the appearance of clinical signs. Typically, this is 5-14 days, although experimentally it can take 28 days or even longer. When

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the disease occurs in pigs kept in large groups, the first clinical cases are often missed. These individuals expose the rest of the group to a very large challenge and a week later, when the farmer first notices the disease, it is often described as a sudden explosive outbreak present in 20% of the pigs in a pen and in several pens. The excretion of liquid faeces containing mucus and often blood is a typical feature of the disease. Affected pigs rapidly become dehydrated, and muscle wasting can be very marked. They can die within 12 hours of the first clinical signs, or after a protracted illness. If left untreated, more than 90% of pigs will become affected and 30-40% will die.

THE PREVALENCE AND COST OF SWINE DYSENTERY

Obtaining evidence of the prevalence of swine dysentery has proved to be a difficult exercise. Swine dysentery is usually seen as an enzootic disease in herds which have been established for many years. It follows, therefore, that control measures have already been devised and are now in constant use. There is no national recording scheme which would record the number of affected herds. In addition, some herds may have swine dysentery without the owner being aware of it. A number of the growth promoters, which are at present included in most pig feeds, have activity against T. hyodysenteriae. It is possible, therefore, that a low level of infection could exist in a number of herds, but be masked by the growth promoting drugs.

A major cost in the control of the disease is the use of chemoprophylactic drugs. It has been calculated that at 1982 prices, continuous medication from weaning to slaughter with anti-dysentery drugs costs between £1.52 and £4.74 per pig (Lysons, 1983). The range reflects the choice of drugs used and the weight of the pig at slaughter. It has been assumed that enzootic swine dysentery causes a reduction in the productivity of the pig herd and it was possible to measure this in one study (Wood and Lysons, 1986). Before the entry of swine dysentery into the herd, the feed conversion efficiency ratios of the growing pigs were comparable with similar herds recorded in the Meat and Livestock Commission (MLC) recording scheme. Similarly, after the disease had been eradicated by medication and cleaning, the herd was again comparable with other MLC herds. During the period when swine dysentery was present, however, the feed conversion efficiency ratio of approximately 3.0:1 deteriorated by 0.58, equivalent to a cost of £7.31 per pig. Since there were only a few pigs with clinical swine dysentery during this period, it was assumed that subclinical disease was mainly responsible for the poor production figures. In this herd the cost of veterinary care and medicine was £1.38 per pig, so in this case, the cost of poor productivity was approximately 5 times the cost of the drugs used. The effect of sub-clinical disease on production figures would, of course, vary with the level of challenge in each herd.

A number of methods have been used to attempt to assess costs and prevalence of swine dysentery. These comprise:

1. Questionnaires. In the USA questionnaires have been sent out to pig farmers. From the replies it was calculated that the cost of swine dysentery in 1976 was $64m per annum (Harris, 1977).

   In the UK, Taylor (1984) sent a questionnaire to members of the Pig Veterinary Society. Even though the response was poor, only 10 practitioners replying, this represented the veterinary care of 7% of the UK pig herd. The results of this survey are given in Table 1.

Table 1. Data obtained on swine dysentery in UK pig herds (from Taylor, 1984)

Type of herd	Breeder/ fattener	Weaner/ producer	Fattener only
Number of herds	207	82	18
Number of infected herds (%)	31 (15)	22 (27)	17 (94)
Number of sows	51,317	8,838	-
Number of sows in infected herds (%)	11,045 (21.5)	3,568 (40.4)	-
Number of fatteners	-	-	53,250
Number of fatteners in infected herds (%)	-	-	53,050 (99.6)

2. Serum surveys. Egan et al. (1982) used serotype-specific antigens in an ELISA, to measure serological response to T. hyodysenteriae in more than 2,000 sera collected from slaughterhouses in the states of Iowa, Missouri and Illinois in the USA. These three states contain approximately 45% of the pigs in the USA and between 30-40% of herds from them were infected with swine dysentery.

   In the USA most isolates of T. hyodysenteriae conform to two serotypes, whereas in the UK many more serotypes are present. Therefore it would not be possible to conduct a similar survey in this country.

3. Market surveys. Surveys carried out by professional market research organisations are often considered to be expensive. In the case of swine dysentery (and other diseases), it may be possible to use existing market research carried out for other purposes. Data can be bought from large scale professional surveys. This can be a cost-effective method of obtaining an estimate of prevalence of swine dysentery. Taylor Nelson Agriculture* for example, make yearly visits to 500 pig farms including representative numbers of large, medium and small units. The drugs used for growth promotion and for therapy are recorded. Data for the period 1983 to 1985 can be obtained for around £3,500, depending on exactly what information is required.

   Such surveys are regularly used by pharmaceutical companies, wishing to monitor the sales of their products and those of their competitors. The drugs used to control swine dysentery are easily recognised and it is hoped that by analysing this kind of survey an estimate of the number of herds with swine dysentery can be obtained. From this, the prevalence of the disease in the UK could be deduced.

RESERVOIRS OF INFECTION

The pig

Pigs with swine dysentery which are not given medication excrete large numbers of organisms (10^9 bacteria per gram faeces) and an animal may take

*Taylor Nelson Agriculture, Taylor Nelson House, 44-46 Upper High Street, Epsom, Surrey. KT17 4QS several weeks to recover. Recovered animals continue to excrete T. hyodysenteriae in the faeces. Songer et al. (1978) reported that pigs that had no clinical signs of swine dysentery for 70 days transmitted the disease to susceptible sentinel pigs. It must be assumed, therefore, that pigs will continue to excrete for several months.

Buying in infected stock appears to be the most common method of introduction of the disease. Thereafter, breeding stock may serve as a reservoir of infection and sucking pigs may pick up the organism; it does not multiply sufficiently to precipitate clinical disease in unweaned pigs, probably because the conditions in the large bowel are not ideal for growth of T. hyodysenteriae, although there may also be a small amount of protection passed from sow to piglet by colostrum and milk.

In the crowded conditions of fattening pens infection levels build up. The severity of swine dysentery as a clinical problem on a farm, or within buildings on the same farm, appears to correlate with the degree of exposure of the pigs to faeces. Pens with slatted dunging areas or deep straw appear to have the least problems. Hot weather and poorly ventilated buildings result in pigs wallowing in the dunging areas, and this can lead to an outbreak of clinical disease.

Other animal and insect vectors

T. hyodysenteriae appears to colonise the gut of the mouse and possibly the dog, and is thought to be spread via passive carriage by other animals and insects. Experimentally infected mice can carry the organism for many months (Joens, 1980). One study showed that 45% of mice were still harbouring the organism in their caecum 7 weeks after inoculation (Lysons, 1984). The organism has been isolated from wild mice caught on farms with enzootic swine dysentery (Joens & Kinyon, 1982; Taylor, D.J. & Lemcke, R.M., pers. comm.). One study (Glock et al., 1978) showed that oral inoculation of dogs resulted in faecal shedding of T. hyodysenteriae for 13 days.

Another category of vector is one which appears to carry the organism passively. Following experimental infection, the organism could be recovered from the faeces for 2 days in rats, 8 hours in birds, and 4 hours in flies (Chia, 1977). Flies also appear to be able to carry the organism on their legs. In this category, an important passive vector of the disease is man. Disease is undoubtedly spread by infected pig faeces carried on boots and on cleaning utensils.

Survival of T. hyodysenteriae in the environment

Even though it is a fastidious, anaerobic bacterium, T. hyodysenteriae can survive well in moist, cool conditions. Chia and Taylor (1978) demonstrated that T. hyodysenteriae will survive in faeces diluted in water for 61 days at 4°C. Temperatures above 15°C reduced this to a week or less. Egan (1981) found that the organism could survive in soil for 18 days at 4°C but it appears to be very sensitive to drying and is killed by most disinfectants at standard concentrations (Chia, 1977).

CONTROL OF SWINE DYSENTERY

Medication

Swine dysentery responds to medication (Table 2) but the drugs of choice are usually expensive. It is necessary to treat all of the animals at risk, and this is usually done by incorporation of the drug antibiotics in the feed. Anorexia is a prominent feature of clinical swine dysentery, and therefore parenteral treatment, or water medication is necessary in the early stages of an outbreak. Theoretically, water medication is preferable, as affected pigs still drink; unfortunately it is very expensive and on many farms is not a practical proposition.

Once the disease is under control, it is necessary to continue medication in feed as a preventative measure. Even so, further outbreaks can occur. Commonly this is brought about when resistance to the antibiotic develops. Alternatively, concurrent disease can result in the appearance of clinical swine dysentery; for example pneumonia will cause a reduction in the pig's appetite and hence its drug intake, and the animal will then succumb to swine dysentery.

Table 2. Drugs commonly used for swine dysentery in the UK

Drug	Proprietory name (distributor)	Method of administration*
Dimetridazole	Emtryl (May & Baker)	WF
Lincomycin	Lincocin (Upjohn)	PFW
Ronidazole	Ridzol (Merck, Sharpe & Dohme)	WF
Tiamulin	Tiamulin (Leo)	PWF
Tylosin	Tylan (Elanco)	PWF

*Administration: P parenteral, W water medication, F feed medication.

Eradication without depopulation

Eradication of swine dysentery on an individual farm without depopulation has been based on the following assumptions:

(1) that high level medication of an infected pig with an effective antibiotic will eliminate *T. hyodysenteriae* from that animal;

(2) that effective measures can be taken to counter the reservoirs and methods of spread of *T. hyodysenteriae*; and

(3) that by taking reasonable precautions, the disease will not be reintroduced into the herd.

A number of attempts at eradication have been made. A report by Wood and Lysons (1986) describes one such attempt in detail, and lists references to other attempts. Methods have varied, but in general the following steps are taken:

(1) All pigs on the farm are given medication for the duration of the eradication campaign.

(2) Those animals, usually breeding stock, which are singled out for elimination of *T. hyodysenteriae* from their large intestine are given more intensive treatment, preferably by water medication.

(3) The animals in (2) above are considered "clean", as are their offspring. They are put into pens that have been thoroughly washed, disinfected and dried, and are kept separate from "infected" pigs, sometimes only by a single empty pen. Care is taken to ensure that boots and cleaning utensils in the clean area do not become contaminated.

(4) The process is continued until all the "infected" pigs have been sent for slaughter. At that point all antibiotic medication is removed.

(5) Rodent and fly control measures are instituted.

(6) Once the eradication process has been completed care is taken to ensure that all pigs brought onto the farm are from swine dysentery-free sources. In addition, precautions are taken which aim to minimise the number of visitors to the farm. Those people who do come in must either change into boots and protective clothing supplied by the unit, or else must thoroughly disinfect their own footwear.

Considerable numbers of successes have been publicised; usually in the farming press. Undoubtedly, most of the failures have not. Where failures have occurred, a second, or even a third attempt can be successful (Muirhead, M.R. pers. comm.; Heard, T.W. pers. comm.). The success of these ventures relies heavily on the knowledge of the epidemiology of swine dysentery. On the basis of the successes, it must be concluded that our knowledge of methods of spread is essentially complete and correct.

Problems associated with the control of swine dysentery

In general, swine dysentery has become easier to control as housing and husbandry conditions have been improved in the national herd. New, effective drugs have from time to time appeared on the market. Many of these have been dramatically effective initially, only to lose their clinical efficacy with time. The newer drugs have usually been more expensive. At present, there is widespread resistance in T. hyodysenteriae to tylosin, and dimetridazole has lost much of its efficacy on many farms. Resistance to lincomycin is widespread in the United States but less so in the UK. It is difficult to persuade many compounders to use lincomycin because there have been a number of incidents where small amounts of this drug used in pig feeds have "carried over" into batches of cattle feed made at that same mill. It is thought that as little as 1 ppm of lincomycin can affect the rumen flora and cause a dramatic reduction in milk production of dairy cows.

A further problem has been in the toxicity of a number of these drugs. Carbadox has been withdrawn from the UK market because of its potential carcinogenic properties and the Food and Drug Administration has banned the use of dimetridazole in the USA for similar reasons. Public concern about antibiotic residues in meat is particularly relevant to swine dysentery control. There is little doubt that the majority of antibiotics incorporated in feeds for pigs close to slaughter, is for prevention of swine dysentery.

Vaccination would appear to be a more acceptable method of control of swine dysentery because it would remove the necessity for medication with antibiotics close to slaughter. An active immunity needs to be induced in pigs from 5 weeks of age until slaughter 4-5 months later. There have been many attempts to produce swine dysentery vaccines, but until recently none has reached the market. One has been launched in the USA (Parizek et al., 1985) but the continued use of drugs is recommended in addition to vaccination of the pigs. Lysons et al. (1986, 1987) described a vaccine which appears to confer good protection under experimental conditions. If this can be developed as a commercial product, it could be a realistic alternative to chemoprophylaxis.

CONCLUSIONS

Obtaining information on the prevalence and cost of swine dysentery has proved to be a difficult exercise. The different methods, together with their inherent inaccuracies, are described. A promising, and cost-effective, approach is to use a commercially available Market Survey.

The causal agent of swine dysentery, Treponema hyodysenteriae, can survive in a cool damp environment for 2 months. The organism colonises the large intestine of the pig and the mouse, which can act as carriers for several months. It appears that other vectors, such as flies, birds and dogs, can spread the organism passively. Methods of eradicating swine dysentery without depopulation have been based on these studies. The successes and failures of these attempts have indicated that our knowledge of methods of spread is essentially complete and correct.

Control and preventive measures are described. Preferred methods have varied in accordance with changes in the pig industry and consumer pressures may have a marked influence in the future.

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COMPUTERISED PIG DATA RECORDING SYSTEMS AND THEIR APPLICATIONS IN VETERINARY PRACTICE

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Data on reproductive and economic performance is now recorded by the majority of large commercial pig enterprises and analysis of this data is carried out using one of a number of different systems. For many years analysis was undertaken manually but in recent years this method has been superseded by the use of computers. Initially mainframe computers were used because of their ability to store the condiderable quantity of data generated by farms of 250-500 sows. However, with recent developments in their storage capacity, micro-computers are now widely being used to analyse herd records.

COMPONENTS OF COMPUTERISED DATA RECORDING SYSTEMS

Farm records

The first component of any recording system is a suitable method for gathering basic farm data. Originally methods tended to evolve from the sow and feed records used in manual systems. Thus several record data sheets were used to record herd stocking rates, sow and boar breeding data, feed data, economic data, etc.

There is now a growing trend to record breeding data on the basis of daily or weekly events. The daily recording method was developed by Pigtails Ltd, a system originally devised by a group of veterinary surgeons and pig producers. It has the important advantage of simplicity and ease of use, and merely involves the pigman recording each event on a daily work pad. For on-farm systems where the input of data is carried out each week, a weekly record sheet listing details of sows that have farrowed, and were weaned, served and culled also involves a minimum of recording by the pigman and facilitates the input of data into the computer.

It is important that any system encourages accurate recording with the minimum of omissions. The need to duplicate the same data on different record sheets should be avoided as this involves extra work for the stockman, and computers, if correctly programmed are well able to utilise information from a single input. Input involving calculations by the pigman should also be avoided, for example, the weaning to service interval. This should be produced as part of the computer output.

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Preliminary investigations have been carried out on the use of data loggers for recording basic data on the farm and with the increasing sophistication of these instruments they may replace the need for written recording. They would have the additional advantage of replacing the process of data input necessary with manual records.

Data input

If trained personnel are used large quantities of routine data can be keyed into the computer quite rapidly, taking perhaps 30-40 minutes for a week's data from a 250 sow herd. Corrections to existing data and omissions are however, more time consuming and it is therefore essential to have an efficient system for editing data. Fortunately, the latest micro-computers are well suited to this process in contrast with some of the older mainframe programmes where the process of editing can be tedious. It is also important that verification of input data is built into the computer programme. This avoids acceptance of records which would produce serious errors in the analysis. Simple examples are limits set on the size of litters which are acceptable for individual sows, or the number of days between the last recorded service date and the date of the next farrowing. The latter is an essential check when analysing the performance of individual boars.

Computers and computer programmes

There is now a wide choice of programmes and computerised systems available to commercial producers to assist with different aspects of management of a pig enterprise. It is not proposed to describe these in detail but they can be broadly sub-divided into systems located on the production unit and those operated by various agencies away from the farm.

On farm systems

Purchased software: There are a number of firms which currently supply both software programmes and micro-computers to commercial farms. They are appropriate for large units which require computerised aids to management and have suitable office staff who can be trained to deal with data input. The systems have a number of advantages. They are convenient for the farmer and input of data can be carried out at short intervals, usually weekly. Because input can be regularly updated these systems can be used as an aid to the day-to-day management of the unit by producing action and check lists for the pigman. The output produced will be sufficiently up to date to be relevant and useful. Also, analysis of the herd's performance can be carried out at intervals chosen by the manager of the unit to suit his particular needs. The main disadvantage of these systems is that problems can arise with some users if they are not given either sufficient help and support in setting up and maintaining the system, or the correct advice when interpreting the output.

Home produced software: With the expansion of interest in home computing some pig farmers are writing their own programmes to assist with the management of their herds. Providing that the analysis is carefully verified, these programmes have the advantage that they can meet the individual needs of the particular enterprise. For example, check lists can be produced giving the exact stall or pen location of the particular sows and the action to be carried out. It is also possible to have considerable flexibility in the analysis that is produced in order to suit the particular needs of the unit.

Systems operated away from the farm

Bureau service: Several commercial firms offer a data analysis service to pig producers. They are usually based on the submission of farm records to the bureau by post each week. Bureaus aim for a three day turn round of information supplying the producer with results and action lists, each week. The advantage for the producer is that he is relieved of any involvement with data input or with any of the problems that can arise with the functioning and maintenance of computer systems. On the other hand, he cannot produce output immediately on completing the weekly input. The on-farm system has this advantage, particularly when up-to-date action lists are important to the pigman.

Veterinary practices: A data analysis system may form an integral part of a pig health advisory service provided for the unit by its own veterinary surgeon. The advantage to the producer is that advice and investigation into problems of substandard performance are an integral part of the service. Managers of large enterprises have someone with whom they can discuss the operation of the unit and with whom they can share the responsibility when making decisions, particularly those involving the control of disease on the farm.

Feed compounders: Several of the larger feed compounders produce data analysis for pig farmers. They are usually concerned primarily with indices of production and feed efficiency and economic analysis. An analysis of the breeding records of individual animals is not usually carried out.

Meat and Livestock Commission: The Meat and Livestock Commission is extensively involved in monitoring the performance and financial results of both breeding and feeding herds. One advantage of the 'Pigplan' system is that the producer is provided with an analysis of the results of his own unit with the results of the average, and top third of other producers in the scheme for comparison. This gives the producer an excellent guide to the current standard of performance of the unit. In view of the steady improvement in efficiency of production in recent years, it is important that the farmer has adequate information on the changing standards that are necessary to retain a profitable enterprise. MLC pig specialists are available to assist with the interpretation of the results and to give advice on the management of the unit. Monitoring of individual sows and boars is available if required, in addition to the analysis of herd performance. The system of recording is however complex in comparison with some of the modern micro-computer systems.

Universities: A number of University departments have been involved in both development work on new programmes and routine monitoring of units. The Agricultural Economics unit of Cambridge University produces detailed financial results for over 150 units which are published in an annual report which includes an excellent analysis of the current financial situation and the outlook facing the industry (Ridgeon, 1985). The PORCS programme developed at Glasgow University Veterinary School (Pepper et al., 1977) was probably the first programme to analyse in detail the breeding records of individual sows and boars and the growth performance of individual feeder pigs. The programme provides useful information for research and development purposes and is used extensively as a teaching aid for veterinary students. It has, however, not been widely used commercially.

The Edinburgh Pig Model is a programme with somewhat different objectives to the majority of those discussed in this paper. It was developed to assist with management and decision making on composition of diets, feed allowances etc. by the use of a response prediction model. A version of the programme is available commercially.

Output

In view of the capacity of modern computers to analyse data in very great detail, systems often produce considerable quantities of output, often with tables containing a large number of figures. Unless great care is taken with programming and presentation the results can be complex, difficult to interpret and even in some cases misleading for farmers and stockmen who have no knowledge of statistics. Miller (1981) discussed the importance of producing output which is relevant to the stockman and easy for him to understand and use. Output can be conveniently divided into a number of subcomponents but is important to bear in mind that different systems will produce different combinations of these.

Stock lists: These may be produced weekly or monthly and indicate the number of animals currently in the herd in a variety of different categories. These may include pregnant sows, pregnant gilts, lactating sows, sows awaiting service, maiden gilts, boars, piglets, weaners and fatteners, culls from the herd and numbers of replacement gilts, deaths, transfers and sales of finished pigs.

Action lists: These lists are particularly a feature of those systems which update the record input each week. They can be a useful management aid for stockmen working in large units. They include lists of ear numbers of sows which are due to farrow, sows due to be weaned, sows due for service, sows not served 8 days after weaning, sows for testing and observation at 3 weeks and 6 weeks post service, sows for pregnancy diagnosis, sows due for culling, etc. The number of sows and gilts to be served each week is a particularly important target to meet and an estimate as to whether this is being achieved is often provided.

Performance of the breeding herd: This is a major component of most computerised systems and many of the indices used for monitoring sow herds are well established. Some of these have been in use for many years. Detailed indices for assessing reproductive performance have been developed more recently and Wrathall, (1982) produced a comprehensive list of these with appropriate targets. Standardisation of definitions is important and an attempt to do this was made with the publication of the ADAS booklet, Pig health and production recording (1983). This has been updated by the Pig Veterinary Society and is being published as Pig Health Recording, Production and Finance - A Producers Guide. A number of the indices of breeding herd performance in common use are based on the average number of sows present in the herd over a particular time period, for example, the numbers of weaners produced per sow per year. This type of index has a number of disadvantages. The result relies on a correct assessment of mean herd size during the period, something that is not always easy to calculate accurately and the result is unreliable if the herd size is increasing or decreasing. It also consists of a combination of several different components of production which are based on quite different management techniques. It is preferable, as far as possible, to use indices which monitor the results of a particular phase of the production cycle or a particular set of management techniques.

Because many indices of sow performance are well established it is perhaps not surprising to find considerable similarities in the basic output produced by different computer programmes. There are however, considerable differences in the presentation of the results, and in the lengths of time periods analysed. Results are also sometimes expressed as rolling averages, as a cusum, or in graphical form. Most systems produce analysis of several different periods of time for comparison although if this is done on the basis of weekly or monthly figures it can make the interpretation of results difficult.

Performance of individual boars and sows: A comprehensive analysis of the performance of individual boars in a herd was rarely carried out by manual recording systems, owing to the complexity of the exercise. However, with the advent of computers these analyses became possible from ordinary basic sow records, and it is now carried out by most computer based systems. Boar performance usually includes the number of services per week, an analysis of regular and irregular returns, the conception and farrowing rate and the average numbers of piglets born for each boar in the herd. The results are often analysed over a 3 or 6 monthly period though some systems produce a monthly or even a weekly result. In view of the fact that boars will usually have less than twelve matings per month, there is not sufficient data available from such short periods of time for any realistic assessment of a boars performance, except in the case where a boar is infertile. In herds with a large number of boars, interpretation of the results can be difficult especially when these are expressed as a league table and faulty decisions on culling could occur if producers are not given adequate guidance.

Pig keepers have been monitoring the lifetime performance of individual sows for many years often using simple manual recording. The advent of computers has greatly reduced the work involved in this process and a printout of the performance of individual sows is a feature of most programmes. It is suggested that the results can be used to decide if a particular sow should be culled, but because of the fairly low repeatability of litter size born and weaned (Strang and Smith 1979) in practice this may be difficult.

Analysis of the feeding herd: Monitoring the performance of the feeding herd has tended to be secondary to that of the breeding herd. In many respects it is less suited to the process, involving more complex recording and less accurate results. However most computerised systems now offer analysis of the feeder herd as an option. Records are usually based on stock numbers present at the start and finish of a period, transfers in, sales, etc., plus a record of feed used. Micro computer systems with weekly input may record batches or lots of feeder pigs, monitoring their progress through the unit on a weekly basis. Output provides an assessment of the average daily liveweight gain and food conversion efficiency of the herd, feed use and cost per pig sold, etc. The PORCS feeder programme (Pepper et al., 1984) is unusual in that it monitors the date, weight and ear number of all pigs at the weighing prior to sale. From this data and their dams farrowing date, the daily liveweight gain of the herd and the progeny of individual boars and sows can be accurately calculated.

Analysis of feed efficiency and economic performance: An important component of computerised systems is a detailed analysis of the efficiency of feed use and a financial report on the current profitability of the enterprise. The latter includes details of output, variable and fixed costs, gross and net margins for the herd, per sow, and per pig sold. Results may be produced monthly, quarterly, 6 monthly, or yearly.

Special analysis reports: The latest microcomputer programmes have considerably more flexibility in the output they can produce than the original programmes written for mainframe computers. With data for individual sows programmed into a number of separate fields it is possible to examine a number of combinations and permutations. It is possible for example to compare the performance of different groups of sows with certain specified characteristics.

Health reports: Systems vary considerably in the extent to which they record and analyse data on disease. However some systems produce a breakdown of causes of piglet and feeder deaths and the reasons for culling sows.

APPLICATIONS OF PIG RECORDING SYSTEMS IN VETERINARY PRACTICE

The output and results from computerised systems produce information of considerable importance to veterinary surgeons involved in routine advisory visits and preventive medicine schemes. They are particularly necessary for accurately assessing reproductive efficiency as it is not possible to do this by carrying out a clinical inspection of the herd.

The main stages in the use of records are shown in Fig.1.

One of the most critical functions for the veterinary surgeon within this scheme is the correct interpretation of the analysis and the definition of areas of substandard performance. This involves comparing the results of a variety of production indices with established standards and tolerance levels. (Muirhead, 1978; Wrathall, 1982).

Tables 1 to 3 are typical of the type of analysis produced by microcomputers with weekly data input and they illustrate some of the problems involved in the interpretation of results. Veterinary

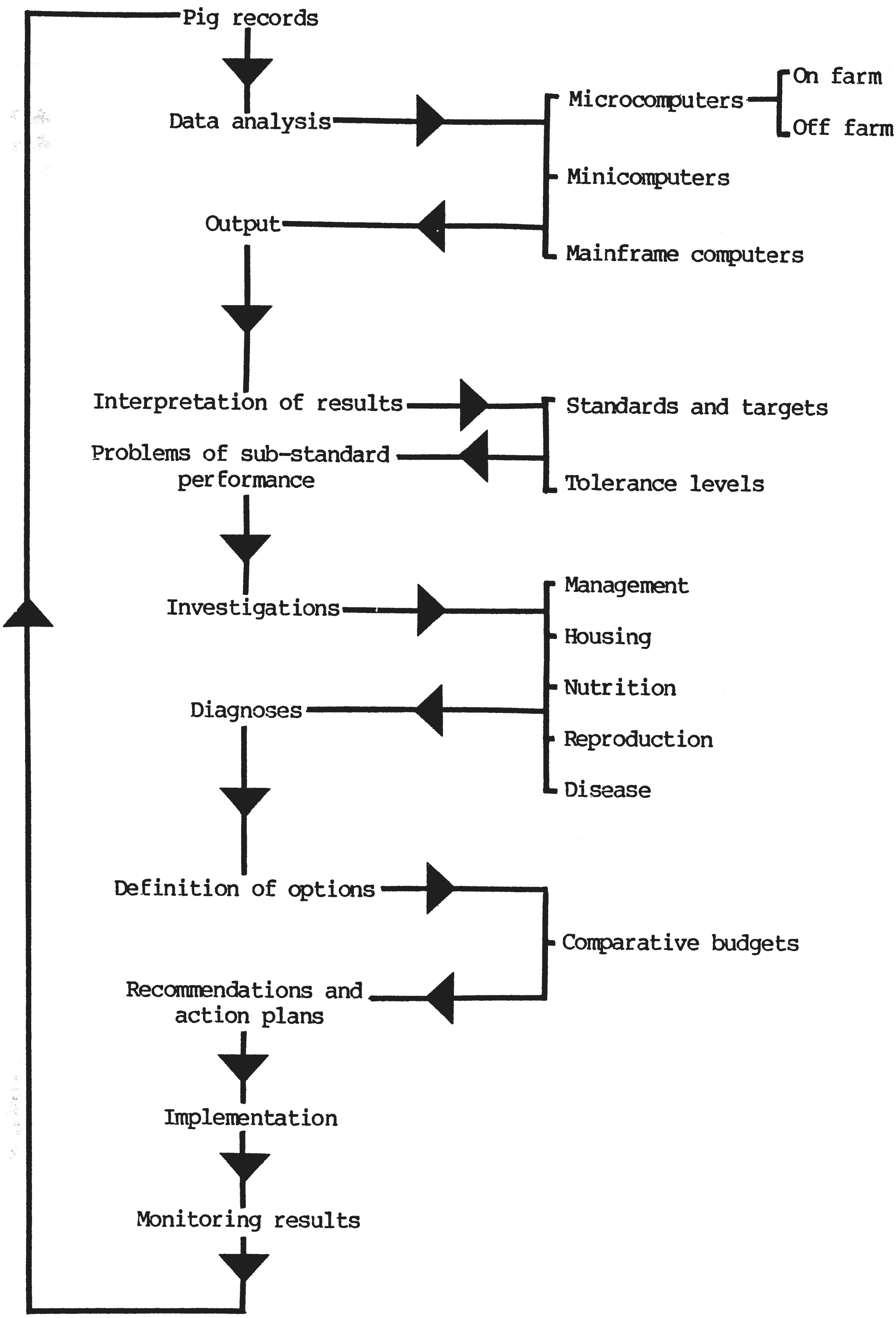

Fig. 1. Application of data analysis systems in Veterinary Practice.

surgeons, advisors and farmers have to become familiar with the extent of the variation that will occur in weekly and monthly figures if they are not to conclude that the herd is improving or declining in performance when in fact it is remaining more or less constant. In Table 1, analysis of numbers born over three time periods are presented for a herd of approximatley 260 sows. The figures for the last week and last month are well below target and the question arises - do these represent a decline in the herds performance? To answer this it is necessary to appreciate the range of figures that would be expected purely by random chance if we analyse a herd with a mean litter size of 11.2 and a standard deviation of 2.80 on a weekly and monthly basis. Using order statistics of normal distribution we can predict that the figure for at least one month in a year would be as low as 10.6 and a figure of 10.1 would be well within the range to be expected from a weekly analysis of only about 12 litters. The figure of 11.2 for the last year is based on approximately 600 litters and indicates that the herd is in fact on target and that there is no indication of a problem of low numbers born in spite of the two low figures produced in the latest analysis.

Table 1. Mean number of piglets born per litter

	Last week	Last month	Last year	Standard
Number of litters	12	50	585	
Piglets born per litter	10.1	10.6	11.2	>11.0

Table 2 shows a set of figures produced from a similar herd on a monthly basis. They too are within the range that would be expected and it is unlikely that the low figures for the three months of July, August and September represent a seasonal variation in numbers born. It is much more likely they are part of the normal random variation.

When herds are monitored on a monthly basis, with roughly the same number of litters produced each month, indices such as numbers born and weaned can be plotted as a control chart. A line should be drawn to represent the lower tolerance limit. This can be calculated from the mean, the standard deviation and average number of litters produced monthly, and is usually set at two standard errors below the mean. For the data in Table 2, the tolerance line is drawn at 10.4 with none of the monthly figures falling below it. The use of control charts for monitoring indices of reproductive performance have been described in detail by Wrathall and Hebert (1983).

Table 2. Monthly analysis of piglets born per litter

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
11.0	11.2	10.8	11.8	11.4	11.4	10.8	10.6	10.9	11.5	11.2	11.6

Table 3 is a typical example of the type of data on individual boars produced by microcomputer systems. Five boars have a recorded farrowing rate below a standard 80% and one is as low as 64%. The farmer may enquire whether the fertility of these boars is poor, as indicated by the figures and whether any of the boars should be culled. Again it is necessary to appreciate the range of farrowing percentages that will be produced when the results of an average of 20 services are analysed, particularly when some boars may have as few as seven services. Statistical analysis of this data indicates that these figures are similar to those that would be expected by chance. The fertility of none of the boars is suspect and the results of further services is likely to confirm this.

Table 3. Analysis of boar performance. 3 month period

Boar number	Number of matings	Percentage of sows farrowing to first mating
1	13	77
2	28	86
3	23	96
4	14	64
5	26	77
6	25	84
7	25	84
8	8	88
9	24	92
10	7	77
11	20	80
12	23	83
13	23	78
14	17	82
15	26	92

In view of the time and expense involved in recording and analysing data, it is vital that when areas of substandard performance are established, the result is not ignored and a full investigation into the factors causing the problem is carried out. This may necessitate investigations into disease, housing, nutrition, breeding and management and may involve collaboration with specialists from other disciplines.

Veterinary surgeons with their longstanding knowledge of the unit based on regular visits, are in a unique position to direct these investigations. Recommendations and possible courses of action should be listed and if necessary a comparative budget of costs and probable benefits of the options should be considered. This means that veterinary surgeons must become familiar with the economics of a pig enterprise, particularly with the costs and benefits of the changes they recommend, and the cost effectiveness of the preventive medicine programmes they initiate.

SUMMARY AND CONCLUSIONS

At present there are a variety of different systems of data analysis in use, and developments are taking place so rapidly in the field of microcomputers that programmes written even three of four years ago are likely to be out of date in the near future.

The trend towards on-farm systems is likely to continue as methods of data input are simplified and systems become more reliable with fewer technical problems.

More critical work is necessary on the presentation and simplification of output produced and in particular in indicating which results have real significance. In some instances this may mean incorporating statistical evaluation into programmes.

Pig producers and veterinary surgeons must be able to recognise areas where there is substandard performance and instigate appropriate remedial action. Units cannot afford to fall behind the results achieved by other producers in the industry for too long otherwise they run the serious risk of joining the large number of pig enterprises that have gone out of production in the past twenty years.

The effective monitoring of a units performance using an up to date system of data analysis is a key part of the process of maintaining an economically viable unit.

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COST BENEFITS OF PIG MANAGEMENT MEDICINE SCHEMES

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By defining disease as any factor which inhibits the true genetic potential of an animal, it is clearly evident that within pig husbandry/management there is potential for significant improvement. The farmer keeps livestock principally for a financial return on his investment, thus the treatment of disease by the removal of inhibitors of performance must give a realistic financial return. The causes of many of the important disease syndromes are multifactorial, where infectious disease often plays a subordinate role to deficiencies of management.

In management medicine schemes the emphasis is on the identification of the economically significant limitations on productivity and the proposing of strategies to remove the factor causing depression in the animals' potential. The manager is the controlling influence over the productivity of the unit since he can control his resources (feed, stockmanship, housing, genetics) and micro-organisms in the environment. Using this approach, the centre of any disease control programme hinges on the education, motivation and encouragement of the unit manager to optimise his resources. If they are inadequate then the feasibility of acquiring new housing, drugs, genetics and staff etc. must be considered.

Muirhead (1980) discussed the approach and economics of the advisory visit in preventive medicine on a pig unit. This format is now well accepted as a basis for an advisory service on the pig farm. The problem is to convince the paying farmer that a preventive medicine scheme can make a positive contribution to the economics of his farm. However, the veterinary surgeon cannot produce unassailable figures to prove that management medicine schemes are cost effective.

In attempting to evaluate the cost benefits of management medicine schemes there is a problem in statistically assessing results because the data have evolved from a pre-selected group of people interested in these schemes and who are striving to improve performance. By examination of physical performance figures of a few key areas on the farm, some valid indication of the value of these schemes can be obtained by showing the productivity improvements made on farms in the initial period after embarking on a scheme. Further evidence can be obtained from comparative data of productivity figures from clients using a practice scheme as opposed to those who just use a veterinary practice as an emergency service. Furthermore, results from clients on a scheme can be compared to national recording schemes, and these figures can be evaluated on a model to give an indication of the financial return from this approach.

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Further indications of the benefits of management medicine schemes can be obtained from the percentage of pigs requiring in-feed medication since this indicates the degree of disease control on a unit. When these benefits are compared to the cost of providing the service then it is seen that there is a significant financial return, but this is difficult to statistically prove because one is working from a pre-selected group of individuals.

MANAGEMENT EVALUATION

In the clinical examination of the unit, assessment of the management and stockmanship is of major importance. Experience shows that two units of vastly different facilities can give the same physical performance, or alternatively two identical units can give widely divergent results. This observation substantiates the opinion that the manager is the critical factor in a unit's performance. This is relayed to the pigs via the standard of stockmanship. No matter how acceptable a system may be in principle, without confident diligent stockmanship, the performance and welfare of the animals cannot be adequately catered for. Seabrook (1984) discussed the physiological interaction between the stockman and his animals and its influence on the performance of pigs. He found that pleasant, consistent and confident handling led to a good relationship which was correlated with improved performance. The good manager identifies shortfalls and can compensate for the inadequacies of the system, whereas the poor manager always expects the answer in terms of a new house, different feed, new pigmen etc., or, all too often, looks to drugs or vaccines as a panacea for all depressions in productivity. If this type of pigman allows drugs to continually cover up his management failures, rather than tackling the root of the problem, we get a "drug dependent pigman". If a problem arises this is seen as a failure of the drugs rather than management inefficiencies. The good manager foresees potential problems and adapts the system; in contrast, the poor manager encounters the problem and has to take corrective action - "management by crisis".

Most of the infectious diseases of intensive pig production require a stress factor for the emergence of the clinical disease. Most units already contain the organisms which could produce the main diseases of intensification such as enzootic pneumonia, rhinitis, meningitis, dysentery, mastitis, and scours caused by *Escherichia coli*. These conditions will only be evident if there is some shortfall in the housing, stocking density, feeding, or ventilation which in turn leads to stress and poor health and productivity. With the ever increasing stocking density in pig housing and the stress this causes, the adoption of small modules holding only one or two weeks' production helps to stabilise the microbiological pathogen profile in a group of pigs and decreases the risk of infection.

It must be borne in mind that infectious conditions are not the major factors affecting the return from a unit, but rather the efficiency of food utilisation since it accounts for 61% of production costs (MLC 1986). The other significant variable costs are electricity and gas at 2% output. In terms of fixed costs, labour is the greatest overhead at 8.5% of output. Interestingly, veterinary and medicine costs are only 1.6% of output.

On a long term basis the major part of a management medicine programme is to anticipate potential shortfalls and to put in a programme to limit the risk of performance decreasing below the target level. In the long term, one is trying to evolve a "fool proof" system where disasters are less likely to occur than previously.

MANAGEMENT MOTIVATION

As units become larger, the financial risk of introducing a new infectious agent onto a unit becomes greater; hence many units construct barriers to control potential pathogens entering the unit. One of these is not allowing visitors onto the unit. This action, however, has precluded one of the unit's greatest sources of performance improvement: judgement by peers. It is now rare for farmers to walk around their neighbours' or friends' pig units to give constructive criticism. The veterinary surgeon is one of the few "outside people" examining many pig units. Thus, he plays an essential role in helping to motivate and encourage the manager. Many managers are isolated, and do not see significant numbers of outside units to be able to make critical, valued judgements.

It is important to give praise if a job is well done; this is a great incentive. If conditions are not correct the route forward is education. A manager cannot run a unit beyond his own level of knowledge and expectation. On-farm education is important for the individual manager and personnel on a unit. Deeper insight into management can be obtained by running seminars within the practice as part of the management medicine programme. Within the practice, regular training seminars are held for managers of several units where they meet together for an afternoon each week, and where they can be influenced by peer pressure in a training group.

METHODOLOGY

For comparative purposes, the data extracted from client records were as follows: number of pigs born alive per litter, suckling pig mortality, pigs weaned per sow per year, fattening pig mortality, food conversion efficiency and daily liveweight gain. These variables were studied because they indicated the physical productivity of a unit and most clients had recorded these factors. If all the data were not available from a client they were not included in the figures. The recording systems used were a conglomeration of national schemes, feed company schemes and the practice's own private manual and computerised systems. The financial advantage of any improvements was related to Meat and Livestock Commission (MLC) averages (MLC 1986a); using a model, a financial evaluation of these was obtained.

RESULTS

New clients

By examining new clients' records, an indication of possible improvements over the first 2 years was assessed (Table 1). It is to be expected that the improvements with new clients would be greater than with existing clients, because new clients started using the practice to solve an on-going problem. Commonly, when new clients were examined, the problem with which they initially approached the practice was not the major economic limitation of the unit.

Table 1. Performance improvement with new clients over a 2 year period (11 farms, 2007 sows)

	Original performance	2 year performance	Improvement
Pigs born alive/ litter	10.37	10.83	4.44%
Suckling pig mortality	13.9%	11.0%	20.8%
Pigs weaned/sow/year	19.34	21.9	13.23%
Fattening herd mortality	4.87%	3.07%	36.96%
Food conversion efficiency	2.80	2.52	10%
Daily liveweight gain	543 g	619 g	14%

When these results are examined, it is seen that initially these farmers were below the performance of our own clients (Table 2) and MLC average results (MCL 1986a). Interestingly, the area making the greatest improvement were mortality in the suckling and fattening herds: an area of traditional veterinary concern.

Table 2. Performance of clients using a practice management medicine scheme compared to national averages (From: MLC 1986)

	Management medicine farms	Meat and Livestock Commission average	% Improvement
Pigs born alive	10.88	10.39	4.7%
Farrowing house	9.49%	11.64%	18.47%
Pigs weaned/sow/year	22.79	20.63	10.47%
Fattening herd mortality	2.41%	3.04%	20.72%
Food conversion efficiency	2.53	2.72	6.99%
Daily liveweight gain	605 g	583 g	3.77%
No. sows No. herds	13030 47	71822 421	-

Emergency service clients

Table 3 shows the differences in performance between clients using the practice purely for emergency services versus those using management medicine schemes. This would include animals that are acutely ill and also acute outbreaks of disease where treatment is necessary. There is no ongoing rapport between the farmer and the veterinary surgeon other than to solve an acute clinical condition.

Table 3. Performance of clients using a practice management medicine scheme versus clients using emergency services only

	Management medicine scheme	Emergency services	% Improvement
No. sows No. farms	13030 47	3201 13	
Pigs born alive/ litter	10.88	10.54	3.23%
Suckling pig mortality	9.49%	11.6%	18.19%
Pigs weaned/sow/year	22.79	19.74	15.45%
Fattening herd mortality	2.41%	3.8%	36.57%
Food conversion efficiency	2.53	2.84	10.92%
Daily liveweight gain	650 g	574 g	5.23%

Management medicine clients

In Table 2 a comparison is made between the average results from the farms on management medicine schemes as compared to MLC averages. This includes 47 herds of 13030 sows. Here again there are significant improvements over the MLC average.

COST BENEFITS

To try and evaluate the advantage to clients of management medicine schemes, financial results extracted from MLC results (1986a) were compared to clients' results (Table 2). The value of each extra pig produced was assessed to be the gross margin, that is, the profit after taking into account feed costs and other variable costs. Variable costs include veterinary services, medicine, transport, electricity and gas, water, straw and bedding, and miscellaneous small items. Fixed costs have not been subtracted from this figure since it is judged that these are on-going costs, regardless of whether or not extra pigs are produced. Fixed costs include labour, contract charges, buildings and rent, machinery and equipment, finance charges, stock leasing fees, insurance and sundries. The results for pigs born alive, and farrowing house mortality are not included in the financial assessment because these figures are combined in the pigs weaned per sow per year figure.

The fattening herd assessments are made on the decrease in fattening house mortality where the value of a dead pig is the cost of production to reach that stage. Also, within the fattening herd, the value of the food conversion efficiency is considered. Based on MLC (1986a) figures, with feed costing 15.68 p per kg, an improvement of 0.1 in food conversion to 90 kg is worth £1.41.

Table 4 shows the physical advantage to clients using the management medicine schemes compared to MLC average results. This shows that the extra pigs produced per sow per year are worth £2158, the decrease in fattening mortality worth £538.78, and the decrease in food conversion efficiency worth £5961 (this is equivalent to £3.80 per pig fattened). The average herd size in the survey was 277 sows, hence the average value per farm was £23,982. It is seen that the major contribution to the financial improvements is due to the increase in food conversion efficiency. Again, since feed accounts for in excess of 60% of cost of production, increases in food conversion efficiency can considerably improve overall enterprise profitability. Clients' accounts were analysed to calculate the cost, per pig sold, of the management medicine schemes. The costs calculated were the advisory and educational fees only. Drugs, vaccines and other animal health products were excluded. This was £2.12 per sow, or 9.3 pence per pig produced, or 0.15% of output. Muirhead (1986) calculated similar costs of pig advisory services as 0.17% of output in 1976. Guise (1986) showed that farms receiving routine veterinary visits had lower veterinary costs (of advice and drugs) in total: £17.09 versus £22.96/sow.

Table 4. Financial advantage of preventive medicine schemes: advantage related to Meat and Livestock Commission (MLC) figures

MLC figures	
Each extra pig produced	£9.90
Each 0.1 improvement in food conversion efficiency (pig to 90 kg liveweight)	£1.41
Average value of dead pig (40 kg liveweight)	£37.57
Advantage of management medicine scheme/100 sow/per annum	
Extra pigs/sow/year	£2158
Decrease in fattener mortality	£538
Increase in food conversion efficiency	£5961
Total	£8657*

* Equivalent to £3.80/pig sold

FEED MEDICATION

An indication of the effectiveness of a control programme in limiting disease syndromes on a unit must be the necessity to medicate feeds. In an MLC survey (MLC 1986b), covering 848 farms, the inclusion of medication in weaner and grower feeds was studied (Table 5). This shows that a very high proportion of weaner and grower feeds were medicated. If the categories of medication for treatment for a specific disorder, and medication as a general insurance against disease (prophylaxis), are combined we see that 51% of first stage fattening pigs, 44% of second stage and 21% of fatteners are medicated, which gives an overall average of 38.7%. Furthermore, a further 27% included medication for growth promotion in the fattening feed.

Table 5. Meat and Livestock Commission survey of the percentage of feeds medicated

	1st stage weaners	2nd stage weaners	Fatteners
Medication for treatment of specific disease	27%	26%	15%
Medication as a general insurance against disease (prophylaxis)	24%	18%	6%
Medication for growth promotion	25%	23%	27%
No medication	24%	33%	52%

Within the practice, all prescriptions for medicated feeds were totalled and compared to the total feed usage by all clients. Eight point four one percent of all feeds used by practice clients were medicated. When one considers that the average cost of including medication in feed is anywhere between £8 and £19 per tonne, and an average of £12.20, this reduction in the percentage of feed medicated is a considerable financial saving. A typical 100 sow herd uses 485 tonnes of fattening feed per year. On MLC figures, 188 tonnes of feed would be medicated, costing £2293, while practice clients would have a medication cost of £497.60. With the constant consumer lobby wanting meat free from antibiotics, moves towards a lower percentage of medication in fattening pigs must be the standard to aim for.

DISCUSSION

The data extracted from practice records show that clients using management schemes achieve above national average performance. How much the improvement is due to the schemes is not possible to determine. The clients of the practice were mostly aggressive, modern operators striving to improve performance. The success of one neighbour acts as an impetus to others. Long term management medicine schemes offer more than peer competition because they try to develop a system where the standard of management has been improved by dedication and motivation, and the chances of problems occurring are decreased.

If even a small proportion of the improvements is due to management medicine schemes, then it is a feasible consideration for a farmer who is trying to increase productivity. The cost to the farmer for advisory/ management medicine is very low at 0.15% of output, yet the expected financial improvements are far in excess of this cost, and this must be the way forward.

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PRACTICAL COMPUTER MODELS FOR ASSESSING PRODUCTIVITY IN PIG PRODUCTION SYSTEMS

W.E. MARSH*

A number of practical computer programmes which address key areas of pig production have been developed by researchers in the Health Care Delivery Systems group at the University of Minnesota College of Veterinary Medicine. Certain models have been designed to evaluate decision options in specific areas such as management of respiratory diseases in growing pigs and voluntary culling of individual sows. A more flexible, stochastic model of a swine breeding herd (PigORACLE) has been developed as an aid to projecting the likely physical and financial performance of individual herds following management changes and/or disease outbreaks. Furthermore, PigORACLE has been designed to work in tandem with PigCHAMP, a production and health recording system for pig breeding herds. Together, they can provide an integrated management system capable of providing information useful in evaluating the consequences of possible veterinary interventions in individual herd situations.

COMPUTER MODELS USED IN ANIMAL HEALTH AND PRODUCTION SYSTEMS MANAGEMENT

Various types of computer models and other methods of synthesizing epidemiological data have been reviewed recently (Morris & Marsh, 1985). Two main classes of computer models exist: deterministic and stochastic. Deterministic models are constructed such that they will always generate the same output from a given set of input coefficients. They will yield only the average or expected results for the system being modelled for a particular combination of input levels. In contrast, stochastic models incorporate a degree of randomness due to the deliberate injection of chance into the simulation so that the results of a run are the consequences of many different random events based on long-term probabilities built into the model. For a given set of input parameters there will exist a range of possible outcomes intended to replicate the natural biological variation in the system. The occurrence of extreme outcomes often provides valuable insight into the operation and stability of the system being studied.

A second criterion often used in classifying computer models relates to whether they include some means of incorporating the passing of time (dynamic), or are simply concerned with the state of the system at one point in time (static). Using these dual criteria, the operational characteristics of any particular model will cause it to be classified into one of four possible groupings:

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a) Deterministic - static (simplest conformation)
b) Deterministic - dynamic
c) Stochastic - static
d) Stochastic - dynamic (most complex)

Both deterministic and stochastic models have been used in the study of livestock production systems, and each type has its applications. The choice of which approach is most suitable depends upon the purpose of the user. Also, although the purist might argue that the only true computer models are dynamic, a static model can often provide insight to health and management problems.

TWO EXAMPLES OF DETERMINISTIC - STATIC MODELS

The increased availability of electronic spreadsheet programmes on microcomputers has popularised the construction and use of deterministic models as effective budgeting and management tools. The great advantage of the electronic spreadsheet is that a model can be constructed in a matter of a few hours by a computer novice. The better spreadsheets have many advanced features which simplify model development, and make them an ideal starting point in modelling.

RESPITE - a computer-aided guide to the prevalence of pneumonia in pigs

RESPITE (Morrison & Morris, 1985) provides an example of a useful spreadsheet application which was developed in a matter of weeks. It was designed as an educational tool to demonstrate to pig producers the expected level of enzootic pneumonia in pig herds which follow specified management practices.

It predicts the percentage of pigs in a herd that have pneumonic lesions, typical of enzootic pneumonia, at slaughter inspection. This percentage is not an accurate prediction and should be regarded only as a guideline. Eleven factors that predispose to the development of pneumonia have been selected from the published research. Each of these predisposing factors must be assessed in the farrowing room, nursery room, and the grow-finish area separately.

The programme was carefully designed to display values of input parameters and results of the analysis simultaneously on one computer screen (Fig. 1.) This feature makes the guide very simple to use - even by those who may consider themselves to be "computer impaired." The simplicity of the model and the operational features of the spreadsheet programme permit the displayed results to be updated at almost the same instant at which any input value is changed. This allows users to view the predicted effects of changing many combinations of input variables within a short space of time. The one-screen approach also minimises the amount of paper required to print a hard-copy record of each scenario, if desired. Also, when each printed record is reviewed at a later time, all the input data and associated results are retained together.

		FARROW	NURSERY	GROW-FIN	HELP
2		************************************			
3	SIZE	0	1	1	=A61
4	FLOW	1	1	1	=A81
5	BUYER	0	0	0	=A101
6	TEMP	.39	.49	.63	=A121
7	WIDTH	0	0	0	=A141
8	WALLS	1	1	1	=A161
9	SPACE	0	1	1	=A181
10	DIARR	0	1	0	=A201
11	WASTE	1	1	1	=A221
12	WORM	0	0	1	=B41
13	PRV	0	1	1	=B61

14	--			
15	METHOD OF CALCULATION =B81	RESULTS OF ANALYSIS		
16		SUBTOTAL	RESOLVED	TOTAL
17	FARROWING	18%	16%	2%
18	NURSERY	70%	52%	17%
19	GROW-FINISH	72%	18%	54%
20	PREVALENCE AT SLAUGHTER			73%

E13 Form=1

Width: 10 Memory:208 Last Col/Row:L236 ? for HELP

1>

1 = Help; F2 = Erase Line/Return to Spreadsheet; F9 = Plot; F10 = View

Fig. 1 RESPITE: observations entered and results tabulated

A second important design feature of RESPITE is the availability of HELP screens (Fig. 2.) Each input variable has an associated screen of text which provides a full description of the parameter, plus some suggested values for particular situations. Each HELP screen is accessed by entering a short sequence of keystrokes. When the HELP screen has been read, the user is returned to the main screen by a similar process.

DIARR - Diarrhea is the eighth predisposing factor to be assessed. It has been determined that pigs that have a clinical episode of diarrhea while in the farrowing house are more likely to develop pneumonia than pigs that don't get diarrhea. Similarly, pigs that have clinically evident diarrhea after weaning have an increased risk of developing pneumonia.

If diarrhea is a clinical problem in any of the production areas enter a 1 (one) in the appropriate cells (C10, D10, and E10). If diarrhea is not a problem, then enter a 0 (zero) in the cells.

Enter =B1 to return to the data entry screen.
Enter =A221 to proceed to WASTE information. Enter /QY to exit.

Fig. 2 Example of a RESPITE help screen

Although useful as an educational tool, RESPITE has no economic component and is, therefore, limited in its applicability as a decision aid in making day to day management decisions. However, the techniques involved in contruction of the programme show how the usefulness of a model resulting from regression or path analysis of epidemiologic data can be easily extended to become an interactive microcomputer programme.

PorkCHOP - a computer-aided guide to culling decisions in pig herds

A more powerful economic model is PorkCHOP (Dijkhuizen et al., 1986), which is an economic programme designed to help farmers, veterinarians and other livestock specialists make better culling decisions in pig breeding herds. Based on values entered for certain productivity measures for a particular herd, PorkCHOP quantifies the benefits of a longer herd life, calculates an economic index for ranking individual sows within the herd on future profitability, and provides a recommendation for the maximum number of breedings for those sows which fail to conceive. Data required to run the model include reproductive measures, feed consumption and costs, livestock market values, marginal income tax rates, and prevailing interest rates.

Most breeding sows are not culled because they are no longer able to produce, but because replacement gilts are expected to be more productive. The economic decision rule upon which PorkCHOP is based is that a sow of a particular age (parity number) should be kept in the herd as long as her expected income in the next parity (farrowing) is higher than the lifetime average income of a replacement gilt. This income potential of the replacement gilt cannot be realised as long as the sow is kept in the herd, and thus can be interpreted as the opportunity cost of postponed replacement..

For maximum profitability, a sow should be culled if she would be less profitable in future parities than the farrowing gilt which would replace her. PorkCHOP therefore makes a comparison between keeping a sow for additional farrowings, taking into account the probability of premature culling and death in future breeding cycles, and culling her immediately and replacing her with a gilt of average performance for the herd. It takes the information provided about a specific herd and compares the costs and revenues of each of these alternatives, using only items which differ between the various parity numbers of sows.

As PorkCHOP is a much bigger model than RESPITE, it was no longer possible to present all input and output data in one screen area. Therefore, an alternative method of leading the user through an ordered sequence of input and output screens was used.

Given the availability of a complete 80 column by 24 row screen for entering data for each group of input parameters, there is adequate room to display information in a non-crowded fashion. Also, it is possible to introduce the concept of "default values." Defaults are "normal" or "usual" values which are assigned to each variable when the programme is first started. Although offered an opportunity to change each of these values, the user may wish to run the programme leaving some or all of the parameters set at their default values. First-time users are encouraged to run the programme initially with all values left at the default levels, then to change one or two at a time until they become comfortable with the operation of the programme. In this way they may quickly gain an appreciation of the how the programme output responds to changing values of single and particular combinations of input parameters.

Inspection of Fig. 3 shows the piglet production input screen after the pigs born alive and percentage pre-weaning mortality have been edited under the heading "YOUR CHOICE." Before this was done, the values present were copies of those in the "DEFAULT" columns. The default columns are guarded by a protection feature of the spreadsheet programme which does not allow the user to change their values during the normal operation of PorkCHOP. Experienced users may wish to customise the programme with their own set of default values which are appropriate to their local level of pig production. This requires a working knowledge of the operation of the spreadsheet programme, and, if done, the amount of editing required when running the programme in future sessions will be reduced.

FACTOR 3. PIGLET PRODUCTION Enter as accurate figures as you have available, considering each parity separately.

	DEFAULT		YOUR CHOICE	
parity	pigs born alive(pba)	% pre-weaning mort.	pba	% mort.
1	9.3	15.0	9.1	15.0
2	10.0	14.0	9.4	14.0
3	10.5	14.0	10.2	11.5
4	10.8	14.0	10.5	11.0
5	10.9	15.0	11.0	12.0
6	10.8	15.0	11.1	12.0
7	10.7	16.0	10.9	14.6
8	10.6	16.0	10.5	16.0
9	10.5	17.0	10.3	17.5
10	10.4	18.0	10.3	18.0

Fig. 3 A PorkCHOP data entry screen

In addition to multiple input screens, there are a number of output screens, each with an associated "explanation screen" that is provided as an aid to interpretation of the results. Output screens include analyses of financial losses due to delay of conception, optimum lifespan for average-producing sows, and net benefits of increased lifespan. An innovative approach to economic analysis is the Retention Pay-Off (RPO) Index (Fig. 4.).

After determining the optimum lifespan for individual sows, PorkCHOP calculates the total extra profit of trying to keep a sow until that optimum time (taking into account the risk of removal in each parity), compared with immediate replacement. This total extra profit is called RPO: Retention Pay-Off. The RPO is an economic index that makes it possible to rank sows within a herd on the basis of expected future profitability: the higher the RPO, the more valuable the sow. An RPO below zero (displayed as 0) means replacement is the most profitable option. The RPO also represents the maximum amount that should be spent in trying to keep a sow in case of reproductive failure or health problems. It is a way to avoid spending more than the sow can return.

RPO INDEX OF INDIVIDUAL SOWS

	% productivity in previous (max 3) parities (100% = avg.)				
parity	70%	85%	100%	115%	130%
1	$66	$84	$101	$119	$136
2	50	77	105	132	159
3	28	58	88	118	148
5	0	25	52	80	107
7	0	1	22	46	71
9	0	0	1	16	31

Fig. 4 PorkCHOP RPO index output screen

Reading from the table shown in Fig. 4, it is recommended that, for this particular herd, all sows of parity 5 and above, producing 70% or less of the herd average, should be replaced. At the 85% productivity level, seventh parity sows are only marginally worth retaining, while older sows should be replaced.

A EXAMPLE OF A STOCHASTIC - DYNAMIC MODEL

Using Monte-Carlo programming techniques, stochastic-dynamic simulation models which demonstrate the effects of changing reproductive performance in livestock herds have been developed (Marsh, 1986). The models are based on a skeleton model approach that makes the basic model (ORACLE) suitable for use in a variety of situations (Marsh & Morris, 1985). The core of the skeleton model is the pattern and sequencing of events which are characteristic of the reproductive behaviour of female mammals. The skeleton model may be tailored to fit species-specific characteristics to produce simulation models of different livestock production systems. An advantage of this generic approach to modelling is that once the structure and logic of the skeleton model has been programmed, working models applicable to a number of different species and production systems may be developed much more quickly than if each application were built individually.

Both of the spreadsheet models described above produce output that involves an analysis of the expected performance of animals kept as a production herd. Computations are based on the <u>average</u> productivity of sub-groups within the herd, without detailing the activity of <u>individual</u> animals. In contrast, the operation of PigORACLE simulates the reproductive activity and productivity of individual animals. The reports produced are also couched in terms of a whole herd, but computed by aggregating the activity of each individual animal. More than 100 input variables may be adjusted by the user, and a variety of reports are generated by the programme. The various categories of input variables and reports are shown on the main menu screen (Fig. 5).

```
   P I G                        MAIN MENU                        O R A C L E

    Simulation date ...: 31DEC89      Years simulated ...:   4
    Herd name .........: EXAMPLES     Breeding sows .....: 253
    Livestock valuation: $486956      Replacement gilts .:  55

  DAIRY HERD          CHANGE            GENERATE            AUXILIARY
  SIMULATION          MANAGEMENT        REPORTS             FUNCTIONS
  ------------        ------------      ------------        -----------
10 Simulate Year 1  20 Sow Herd Mgmt      30 Demographics    90 Read  Defaults
11 Show Banner      21 Repl. Gilt Mgmt    31 Reproduction    91 Write Defaults
                    22 Culling Rules      32 Graphics        99 Quit
                    23 Density Functions  33 Performance Indices
                    24 Market Prices      34 Cash Flow Statement
                    25 Accounting         35 Income Statement
                    26 Income Tax         36 Livestock Valuation

          Please indicate your choice:
```

Fig. 5 PigORACLE "main menu" screen

To inspect or edit the values of input variables, the user may enter a number between 20 and 26 at the keyboard. For example, following the selection of menu option 20, the main menu screen will be replaced with the Sow Herd Management screen as shown in Fig. 6. Input variables shown on this screen are numbered between 1 and 19. Following the number, there is text describing the nature of each variable. In the design of the model, care was taken to ensure that each variable was described in terms and units which were commonly used by farmers. This not only enhances the appeal of the model as a practical tool for helping make management decisions, but also improves the likelihood that users will enter values that are appropriate for their own situations. Default values are presented on the right-hand side of the screen. As in PorkCHOP, these values will be used for the next simulation period, unless changed by the user beforehand. The process of editing is a two-stage process: First, the number corresponding to the desired item is entered at the prompt displayed at the bottom of the screen (in this case a number between 1 and 19). Next, the blinking cursor automatically moves to the appropriate line on the screen, erases the default value and waits in the space created for the entry of a new value.

As PigORACLE is written in 'C', a high-level programming language, and is not dependent upon the underlying features of a spreadsheet programme, a function was written to check the value of each entry for reasonableness. Users inadvertently entering absurd or inappropriate values will be alerted with a "beep." A message describing the range of allowable values will immediately appear at the bottom of the screen, and the user is invited to try again.

```
P I G            BREEDING HERD MANAGEMENT PARAMETERS     O R A C L E

                            REPRODUCTION
[ 1] Probability of a sow experiencing difficult farrowing :  5.00%
[ 2] Proportion of pigs born live ........................ : 90.00%
[ 3] Expected pre-weaning mortality ...................... : 11.00%
[ 4] Desired age of pigs at weaning (days) ............... : 28.0
[ 5] Maximum number farrowing crates available per week .. :   20
[ 6] Probability of sow being served at first estrus ..... : 90.00%
[ 7] Conception rate for all services .................... : 85.00%
[ 8] Min. sow productivity index to qualify for re-breeding: 70
[ 9] Maximum number of services for low-to-average SPI sows:  2
[10] Maximum number of services for above  average SPI sows:  3
[11] Probability of a sow aborting ....................... :  2.00%
[12] Pounds of feed consumed per sow per day ............. :  6.0

                 EXPECTED AVERAGE TOTAL LITTER SIZES
[13] First  parity ...................................... :  9.0
[14] Second parity ...................................... :  9.3
[15] Third  parity ...................................... :  9.8
[16] Fourth parity ...................................... : 10.0
[17] Fifth  parity ...................................... : 10.0
[18] Sixth  parity ...................................... :  9.8
[19] Mature sows ........................................ :  9.5

Enter the number of the item to edit or [0] to return to menu:
```

Fig. 6 PigORACLE Breeding Herd Management Screen

Range checking guarantees that each run of the programme will use sensible values for all variables. It offers an improvement over the data entry procedures for the spreadsheet models which will accept absurd values, sometimes producing puzzling results as a consequence. Once PigORACLE variables have been edited to suit a particular production system or farm, they may be stored permanently in a data file on the computer disk with the programme files, using option 91 ("Write default files") from the main menu. On the next occasion when PigORACLE is used, these customised data files may be read in automatically to minimise the amount of editing required to run the programme.

Monte-Carlo modelling

Monte-Carlo modelling is so called because the timing and occurrence of each event is based on chance as in a casino. PigORACLE operates by creating a starting population within the computer which mimics the population of interest in all relevant aspects. 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 distribution. Technically, they are termed pseudorandom numbers because they are produced by the computer as a very long string of numbers that will eventually repeat itself. 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. In PigORACLE, this is achieved by reading the date and time from the computer operating system whenever the programme is invoked. As the operating system stores such information as the number of seconds since a base date, it is always in the form of a large integer which is easily converted to a suitable seed number.

An observation on a uniform distribution is used in PigORACLE to determine whether a sow or gilt becomes pregnant at a particular mating, given the long-term probability of 0.85. (This value corresponds to that entered for variable [7] "Conception rate for all services" in Fig. 6 above.) A random number between 0.0 and 1.0 is generated by the computer, and a test follows. If the random number is greater than 0.85, then the animal is considered not to have conceived. If the random number is less than or equal to 0.85, the event is deemed to have happened, and the animal considered to be pregnant.

If considered pregnant, then a further random observation, this time on a normal distribution, will be used to determine the maximum number pigs that will be born to that particular sow should her pregnancy be carried successfully to term. The exact shape of the normal distribution used in each case will depend on the value of the long-term mean total litter size for the parity number group to which the sow belongs. (See Fig. 6). Other mathematical distributions, including lognormal, Poisson, and exponential are used throughout PigORACLE for determining the outcome and timing of various events in the life cycle of the pig. The distribution selected for each test depends on the nature of each biological process being simulated. Where none of the mathematically-defined distributions is appropriate, a purely empirical distribution derived from field data is used.

Simulating the activity within a breeding pig herd

During the course of the simulation process, PigORACLE maintains a database containing current information on each female animal in the breeding herd. To mimic the passing of time, the simulation model is driven by an internal clock having a base unit of one day. As the clock advances, each animal record is checked. Whenever a due-to-farrow record matches the clock date, the activity of the production cycle of the corresponding sow is simulated. Production cycles begin with a farrowing event and conclude with the prediction of either a future due-to-farrow or due-to-be-culled date. Simulated reproductive behaviour and production input-output data for each sow is simultaneously recorded in a whole-herd database that is used to generate reports at the end of the simulation period.

Simulation periods may begin and end at any dates, and are normally set to run for one calendar year. However, the duration of a simulation run may be set to any length up to six calendar years. As PigORACLE is an event-oriented model, it is able to operate rapidly. For example, using an IBM-AT microcomputer, it is possible to simulate one year's activity of a 100-sow herd in less than two minutes. Actual time for a simulation run will be determined by the clock speed of the computer being used.

PigORACLE AND PigCHAMP: EXTENDING THE USE OF AN INFORMATION SYSTEM

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, 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 models extend the value of the data collected. In theory, models can be linked directly to provide systematic procedures for the synthesis of management options based on an analysis of the current situation.

There has been much discussion over the past two decades concerning the possibility of linking information systems and simulation models to provide comprehensive management tools, but the necessary software has been slow to materialise. PigORACLE was designed specifically to address this need. When the programme starts, it establishes a beginning population by reading the contents of a data file containing information concerning the life history of each female pig in the breeding and replacement herd. Thus, for each sow and gilt present in a herd at the time when the database was established, a surrogate is created in the computer. The appropriate datafile format is shown in Fig. 7.

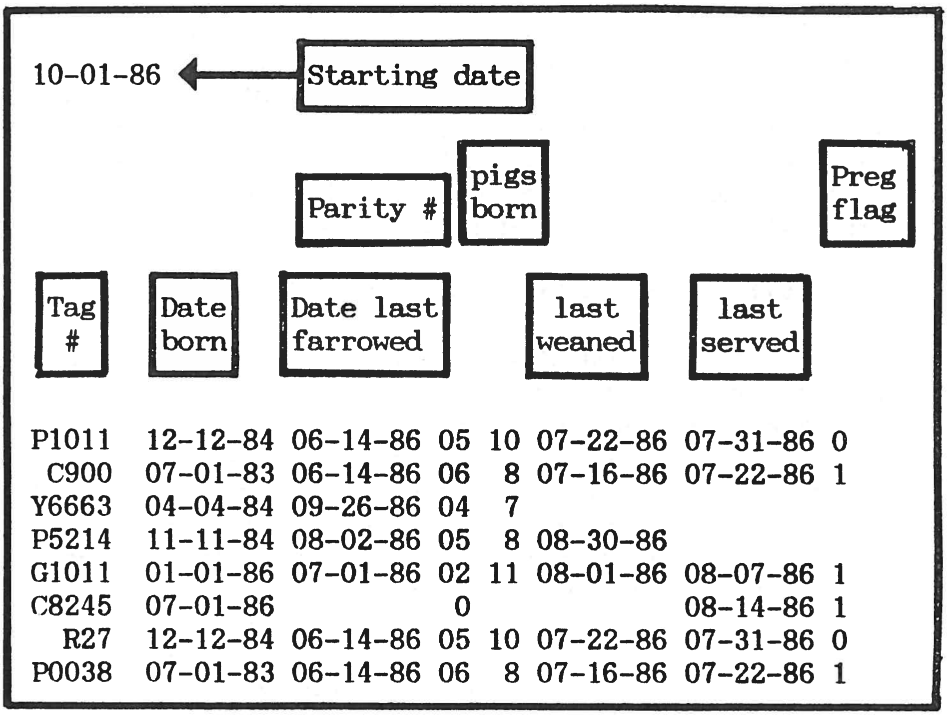

Fig. 7 PigORACLE herd file format

Herd files are stored in the ASCII (American Standard Code for Information Interchange) format. Creation of a suitable herd file may be done manually by using a screen editor to type in data from a card-type record system, or it may be done automatically by using the appropriate option from the computerised system. For example, users of PigCHAMP (Stein et al., 1985) would use the "write text file" facility.

The first line of the herd file must contain a single item, which is the starting date. This is the date to which the production system was updated when the file was created, and it will be the starting date for the simulation runs. Each subsequent line may contain up to eight data items referring to individual sows or gilts: tag number, date born, date last farrowed, parity number, total litter size, date last weaned, date last served, and pregnancy flag (1 = confirmed pregnant, 0 = not confirmed pregnant). This information is sufficient to create a simular herd in the computer which mimics the population of the real herd.

Once the simular herd has been established, the user is at liberty to use PigORACLE to study the likely short-term and long-term effects of changes in health and management of livestock herds. A recommended procedure is to first run the model in a "no-change" mode with all management and financial variables set at current levels to give a baseline situation. As the simulations are stochastic, it is strongly recommended that multiple (five) runs of each scenario (each with a different random number seed) are made. From each set of runs, means (average expected values) and standard deviations (as a measure of risk) of key performance and financial indicators may be calculated.

After the baseline runs have been completed, the user may proceed to simulate the implementation of proposed disease control and management policies and to compare patterns of herd performance with the baseline situation for up to six years in the future. Estimation of means and standard deviations for financial measures, such as enterprise gross margin, permits the user to utilise output produced by PigORACLE as herd-specific data for sophisticated methods of economic analysis. For example, the author has used discounting, decision analysis, and portfolio theory for choosing between disease control options and combining optimum mixes of veterinary interventions as herd health programmes tailored to individual farms.

SUMMARY

The work of members of the Health Care Delivery Systems group has shown that, by using a pragmatic approach, it is possible to develop a wide range of microcomputer tools that can be useful in quantifying the effects of animal disease and management decisions on productivity, and to represent these effects in economic terms. By further economic analysis of the output of such models, the costs and benefits of disease control and management options may be compared, thereby providing a rational base for choosing between options. Interfacing models directly with management information systems kept by farmers and veterinarians enables the simulation of likely performance in individual pig herds.

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OPEN SESSION

THE USE OF DISCRIMINANT ANALYSIS IN A CASE-CONTROL STUDY OF COCCIDIOSIS IN EUROPEAN BROILER FLOCKS

M.F. STALLBAUMER* AND R. SKRZYNECKI**

In recent years the broiler industry has become aware of an increase in subclinical coccidiosis, although the clinical condition is rare. Ad hoc testing of coccidia isolates from sites where subclinical coccidiosis was considered to be a problem revealed that ionophore-tolerant strains of coccidia were widespread. It was not known whether similar strains occurred on farms where coccidiosis was not a problem.

To investigate this question a small case-control study was undertaken. Data from six pairs of 'case' and 'control' farms from the UK, the Netherlands and Italy were analysed by discriminant analysis to study the relationship between subclinical coccidiosis and various management, environmental and disease factors.

This paper describes the techniques used in collection, organisation and analysis of the data in the case-control study. One of the aims of the study was to verify that these techniques were practicable before a larger study was undertaken.

METHODS

Selection of case and control farms

Case definition: Case and control broiler sites were selected from a large number of sites which had been involved in a subclinical coccidiosis monitoring programme. Sites were visited on about the 28th day of the growing cycle and a representative number of birds were culled and examined for coccidia lesions and the presence of oocysts in the caeca. At the same time epidemiological data was collected. Ideally, performance data was collected after the crop was slaughtered, but this was not always possible. A 'case' or 'problem' site was one where lesions and oocysts were found consistently and were more numerous than at other, comparable sites.

Structure of the study: The availability of facilities restricted the study to six pairs of case and control broiler sites. Experience gained during the preliminary monitoring programme identified the UK, the Netherlands and Italy as suitable countries to study. Within each country the area of highest density broiler production was identified. A 'case' or 'problem' site was chosen from the high density area. The

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'control' site was generally another site belonging to the same company which was similar to the 'case' site except that it had no appreciable coccidiosis. A second 'case' site was chosen from a low density broiler production area and was similarly paired with a control. (Fig. 1). Thus each country contributed two pairs of 'case' and 'control' sites to the study.

Data collection

Each site was visited on about the 28th day of the growing period and a sample of litter was collected and submitted to the Lilly Research Centre Limited for anticoccidial drug sensitivity testing. This part of the survey will not be discussed in detail here. During the visit, the site was studied according to the method established during the monitoring programme. A specially designed form including 52 variables was used to record the information gathered during these visits. Birds were culled (5 per 10,000 in a house) to examine for coccidiosis lesions and caecal oocysts.

Personnel carrying out the visits were veterinarians employed by Elanco Products Limited who were trained and experienced in the procedures.

Data organisation

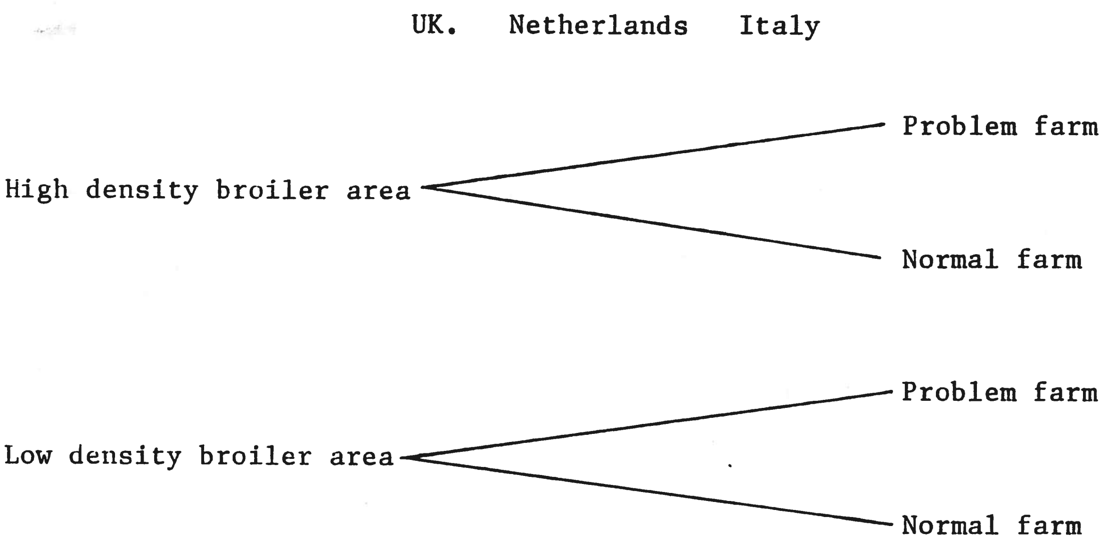
Data from the visit carried out during the study, plus data collected previously during the monitoring programme from the same sites, were included in the analysis.

A computer database was established with this information using the Statistical Analysis System/Full Screen Product (S.A.S./F.S.P.) (S.A.S. Institute Inc. 1985). In all, 49 observations (i.e. site visits) were computerised for subsequent analysis.

Data analysis

Initial regression analysis for association between coccidiosis and hypothesised determinants showed that only the feed assay variable was significantly correlated with disease. That is, if the level of anticoccidial in the feed was insufficient, the severity of disease increased. Thus, a multivariate technique was chosen to study the extent of divergence between 'case' and 'control' groups. Discriminant analysis was the technique chosen (Snedecor and Cochran, 1974). The original classification of sites into problem and non-problem sites did not always prove to be correct when birds came to be examined for lesions. This classification was, therefore, ignored for the purposes of analysis and the population was classified according to the presence or absence of coccidiosis disease criteria. Sites where lesions or caecal oocysts were found were classified into the diseased group. This classification divided the 49 observations so that 30 were in the diseased and 19 in the non-diseased group. The purpose of the discriminant analysis is to correctly assign the observations into the appropriate group by combining the chosen variables in such a way as to maximise the between-group variance relative to the within-group variance.

Fig. 1 Case-control study of coccidiosis in broiler chickens



Variables chosen for inclusion in the analysis were those considered to be relevant to the epidemiology of coccidiosis. Variables were included which related to:

i) the density of the host population - variables 1, 2, 6 and 13,

ii) measures employed to control the parasite population - variables 3 and 4,

iii) the general health of birds and quality of management - variables 7, 8, 9, 10, 17, 18 and 19,

iv) direct or indirect measures of the environment which were thought to influence the cycling of the coccidia - variables 5, 11, 12, 14, 15, and 16.

The 19 variables chosen and their coding are listed in Table 1.

A stepwise procedure was then used to reveal the most important variables for the discriminant function, to determine whether satisfactory discrimination could be achieved using less than the original number of variables. Thus a predictive model, using a number of variables to predict membership of a group (diseased or non-diseased), was formed. The model can be used to classify new observations (broiler sites), of unknown disease status, into groups.

RESULTS

Discriminant analysis significantly differentiated between diseased and non-diseased groups. The 'generalised squared distance' between the groups

Table 1. Variables used in the statistical analysis, their coding and mean values in diseased and non-diseased groups

	Variable	Coding	Mean values Diseased group	Mean values Non-diseased group
1.	No. of houses on site	Actual number	5.6	6.8
2.	No. of birds on site	Actual number	120,000	108,000
3.	No. of days turnaround	No. of days between subsequent crops	12	18
4.	Disinfection score	0 - 3*	0.7	0.5
5.	No. of crops on current anticoccidial programme	Actual number	3	2
6.	No. of birds in house	Actual number	20,880	17,716
7.	Mortality: day 0 - 7	% mortality, including culls	1.29	1.02
8.	Mortality: day 0 - 28	% mortality, including culls	3.25	3.10
9.	Chick quality	0 - 3*	1.26	0.88
10.	Disease	Present = 1, absent = 0	0.22	0.18
11.	Floor type	Concrete = 0, earth = 1	0.17	0.06
12.	Litter type	Wood shavings = 1, straw = 2 paper = 3, other = 4	1.30	1.47
13.	Stocking density	Actual no. of birds/m^2	18.60	16.6
14.	Ammonia score	0 - 3*	1.00	1.10
15.	Dust score	0 - 3*	0.70	1.10
16.	Litter condition score	0 - 3*	1.10	0.70
17.	Broiler condition score	0 - 3*	0.96	1.18
18.	Feathering score	0 - 3*	0.65	0.65
19.	General management score	0 - 3*	1.17	0.59

*0 = very good; 1 = good; 2 = below average; 3 = poor was 10.86, with a probability of misclassification of 6.7%. Nine of the 49 observations were not classified due to missing values. The classification into diseased and non-diseased groups resulted in only one misclassification into the diseased group (observation 30) (Tables 2 and 3).

Stepwise discrimination identified the following six variables in order of importance: General management, number of days turnaround, broiler condition, chick quality, floor type and litter condition. Discriminant analysis using these six variables resulted in the misclassification of nine out of 47 observations (only two observations were excluded because of missing values). The 'generalised squared distance' between groups was reduced to 3.54, with a probability of misclassification of 22.7%. Of the nine observations misclassified, seven were misclassified into the non-diseased group and two into the diseased group (Tables 2 and 3).

Thus using 19 variables, 97.5% of observations were correctly classified and 80.8% were correctly classified using only the six most powerful discriminator variables. The mean values for the variables in the diseased and non-diseased groups are included in Table 1.

DISCUSSION

One of the objectives of this study was to evaluate the suitability of discriminant analysis as an analytical technique for the study of the epidemiology of coccidiosis. Discriminant analysis was highly successful at differentiating between broiler sites manifesting subclinical coccidiosis from those with no sign of disease. This grouping did not exactly match that specified by the case-control grouping. One reason for this is the diverse level of acceptance and recognition of subclinical coccidiosis in the countries studied. In the UK a low level of coccidia cycling is generally accepted, whereas in the Netherlands the diagnostic services classify farms as having coccidiosis when any oocysts or lesions are found during routine post mortem examinations. In Italy clinical coccidiosis would be diagnosed by poultry veterinarians, but the subclinical condition would not usually be monitored.

In the UK, therefore, all the sites were from the diseased group, although the degree of disease varied between 'problem' and 'non-problem' sites. The apparent misclassification of some of the Italian sites, in terms of the case-control study, was because the sites chosen as 'problem' sites had experienced problems in the past but did not always have problems at the time of sampling. The Netherlands samples matched the classification system well because subclinical coccidiosis is carefully monitored. Unfortunately the low density, no problem site (NLLNP) was not included in the case-control study because of sampling difficulties. Subsequent inclusion of data from the chosen site resulted in very accurate classification of the observations.

The mean values for the variables in the diseased and non-diseased groups are probably not very useful as critical values or determinants of

Table 2. Classification of observations into diseased and non-diseased groups by discriminant analysis

Observation	From group	Classified into group: Using 19 variables	Classified into group: Using 6 variables	Case-control classification
1.	D	D	D	UKHP
2.	D	D	D	UKHP
3.	D	D	D	UKHP
4.	D	-M	-M	UKHP
5.	D	D	D	UKHP
6.	D	-M	-M	UKHP
7.	D	D	D	UKHNP
8.	D	D	D	UKHNP
9.	D	D	D	UKHNP
10.	D	D	N*	UKLP
11.	D	D	D	UKLP
12.	D	-M	D	UKLP
13.	D	D	D	UKLP
14.	D	D	D	UKLNP
15.	D	D	D	UKLNP
16.	D	-M	D	UKLNP
17.	D	D	D	ITLP
18.	D	D	N*	ITLP
19.	N	N	N	ITLP
20.	D	D	D	ITLP

Key:

D	=	Diseased group	H	=	High density
N	=	Non-diseased group	L	=	Low density
M	=	Missing values	P	=	Problem area
UK	=	United Kingdom	NP	=	Non-problem site
IT	=	Italy	*	=	Misclassified
NL	=	Netherlands	-	=	Not classified (due to missing values)

Table 2. Continued

Observation	From group	Classified into group: Using 19 variables	Classified into group: Using 6 variables	Case-control classification
21.	D	D	N*	ITLNP
22.	D	D	D	ITLNP
23.	N	-M	N	ITHNP
24.	N	N	N	ITHNP
25.	N	N	N	ITHNP
26.	N	N	N	ITHNP
27.	N	N	N	ITHNP
28.	N	N	N	ITHNP
29.	N	N	N	ITHNP
30.	N	*D	D*	ITHP
31.	D	D	D	ITHP
32	D	D	D	ITHP
33.	D	D	D	ITHP
34.	N	N	D*	ITHP
35.	N	N	N	ITHP
36.	D	D	N*	ITHP
37.	N	N	N	ITHP
38.	D	D	D	NLHP
39.	D	-M	N*	NLHP
40.	N	-M	N	NLHP
41.	D	-M	N*	NLHP
42.	D	-M	N*	NLHP
43.	N	N	N	NLHNP
44.	N	N	N	NLHNP
45.	D	D	D	NLLP
46.	N	N	N	NLLP
47.	N	N	N	NLLP
48.	N	N	N	NLLP
49.	N	N	N	NLLP

Table 3. Classification of observations into diseased and non-diseased groups by discriminant analysis

a) Using 19 variables

		Prediction D	Prediction N	Total
Actual	D	23 100%	0 0%	23
	N	1 6%	16 94%	17
				40

b) Using 6 variables

		Prediction D	Prediction N	Total
Actual	D	21 75%	7 25%	28
	N	2 11%	17 69%	19
				47

D = Diseased group
N = Non-diseased group

coccidiosis. This is because of the diversity of the broiler production methods between the three countries involved in the study. The values of the variables would be more indicative of critical values if the observations were from a more homogenous population, for example, one company. Similarly, the most powerful discriminators, specified by the stepwise discrimination procedure, might be quite different if a different database was used. For example, floor type (i.e. concrete or earth) was an important discriminator. In Italy, where earth floors are not uncommon in the broiler houses, the level of subclinical coccidiosis tends to be higher. The variable "type of floor" would not be included in an analysis of UK data as earth floors are so rare.

Thus the results of this analysis should be used to indicate the value of discriminant analysis as a method for analysing this type of epidemiological data. Nevertheless, the most powerful discriminating variables, identified by the stepwise discrimination procedure, suggest the model is realistic.

The variables included in the analysis were considered to be possible contributing factors to the multifactorial situation which results in coccidiosis. The choice of variables, however, was partly determined by practicality of the data collection and reliability of the measurement.

Other variables, which might have been included, were excluded if the data was considered to be unreliable or if several observations had missing values for that variable. For example, the amount of space a bird has for drinking may have a bearing on the development of coccidiosis, but this is difficult to measure reliably. Instead, indirect measures were used to take such variables into account. Thus, it was hoped that the scoring system adopted to measure the environment, with scores for ammonia in the atmosphere, dust, litter condition, as well as scores for the quality of the birds (chick quality, broiler condition at 28 days old and feathering quality) and a score for the general quality of the management, would reflect the many factors contributing to the environment and health of the birds. Scores were given for other values, for example, type of floor, so that an increase in the score represented an increase in risk of coccidiosis development. Discriminant analysis can accommodate such diverse types of data and had the database been insufficient, it would have been reflected in an inability to correctly classify the observations. Vandegraff (1980), in using discriminant analysis in a case-control study of salmonellosis in dairy herds, successfully employed a similar system for 13 out of the 18 variables included in the analysis.

Having shown that discriminant analysis is a suitable technique for the analysis of epidemiological data pertaining to the incidence of subclinical coccidiosis on broiler sites, the next stage will be to verify the predictive model resulting from the analysis. Further observations may be included without the coccidiosis measures (lesion scores and caecal oocyst estimates) and they will be allocated to a group. The accuracy can then be verified by including the disease variables. Thereafter, more realistic models may be made by widening the database and basing models on specific sections of the data. For example, separate models for the UK, the Netherlands and Italy could be generated. In this way a more accurate approach to the epidemiology of coccidiosis can be made.

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DISEASE SURVEILLANCE UTILISING A COMPUTERISED INFORMATION RETRIEVAL SYSTEM FOR ABATTOIR PATHOLOGY DATA

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Many disease conditions of economic importance which occur in production animals cause pathological changes which are recognisable during abattoir examination. The type and location of the pathological changes frequently relate to a specific disease syndrome and invariably result in the condemnation of the carcase area or organ affected. Detailed information is available for condemnations in all cattle, sheep and pigs slaughtered in abattoirs in Northern Ireland and thus provides data on disease conditions in the population of these production animals. Such diseases can cause a direct loss to producers when whole carcases or valuable parts are condemned, whilst the occurrence of pathological changes in organs (eg pneumonia) may be indicative of diseases which are economically important during the production period.

This paper describes a computerised information retrieval system for abattoir pathology data. The system enables the identification of epidemiologically important trends and quantifies the incidence of important disease conditions occurring during production. The cost of such diseases can be assessed using this system.

MATERIALS AND METHODS

Monthly summaries of abattoir pathology data have been available since 1969 as a result of a computerised data processing system described by Stewart (1969). The system was initially developed on an ICL 1905 computer and subsequently transferred to an ICL 2986 machine. The system was established to process information collected at all abattoirs in Northern Ireland on the causes of condemnation of complete or part carcases. Inspections are carried out by the Veterinary Division of the Department of Agriculture and the system collates data on all cattle, sheep and pigs slaughtered in Northern Ireland. The summaries record the total number of each species slaughtered, the number of specific carcase parts and organs condemned and the reason for each condemnation. The format of the reports consists of a matrix with rows (m) detailing the designated reason for condemnation and columns (n) corresponding to the carcase area affected.

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Individual cells within the matrix record the monthly total within each category. An example for cattle is given in Table 1. For pigs, m = 17 and n = 20. For sheep, m = 21 and n = 16.

Table 1 The reasons for condemnations in cattle slaughtered in Northern Ireland and the carcase area affected

Rows (m)	Columns (n)
Abscesses and Pyaemia	Whole carcase
Actinobacillosis	Side
Arthritis	Fore quarter
Bruising etc	Hind quarter
Cirrhosis	Head
C. Bovis	Tongue
Contamination	Other carcase portions
Decomposition	Lungs
Emaciation	Heart
Fasciolasis	Stomach
Fever and Septicaemia	Intestine
Insufficient bleeding	Spleen
Nephritis and Nephrosis	Whole liver
Oedema	Part liver
Parasitic conditions	Kidneys
Pericarditis etc	Other
Peritonitis etc	
Pleurisy and Pneumonia	
Tuberculosis	
Tumours	
Uraemia	
Others	

The data processing system was initiated and is managed for purely administrative purposes and no database retrieval software exists for statistical and epidemiological analysis. Furthermore, no routine archiving of the database onto backing storage takes place. Retrospective data is therefore only available in the form of hard copy monthly summaries. Preliminary research investigations revealed that complete records were only available since January 1976 due to deficiencies in the manual filing system used.

Data from January 1976 was logged onto a VAX 11-750 super mini-computer via the central data processing unit of the Biometrics Division. It was possible to log the information directly from the summary reports without manual transcription. Data was logged in duplicate to enable validation by a "Key-to-disc" program.

A program written in FORTRAN 77 was developed to extract the data from the primary files and manipulate it into a form suitable for analysis by the statistical software package, GENSTAT. This package enables basic statistical summaries of data and also more advanced statistical analysis such as analysis of variance and multiple regression. The values held in the initial matrix were converted into percentages of the total number of each species slaughtered on a monthly basis. Initial analysis involved the production of average annual incidences of the reasons for condemnation of each carcase part over the 10 year period. Average monthly incidences were also produced for the same period. Linear combinations of such variables were similarly produced and analysed. The results were available in both tabular and graphical formats and enabled overall trends and seasonality patterns to be easily assimilated. Seasonality patterns for individual years were also produced.

The availability of a complete set of monthly data over a 10 year period enabled complex time series analysis of the database. This was achieved by a specially written FORTRAN 77 program operating on extract files of monthly data held in the GENSTAT files. This extensive program enables basic trends and seasonality patterns of any linear combination of variables to be examined. Comprehensive facilities exist to examine rigorously autocorrelation structures and subsequently to combine months (eg bi-monthly, quarterly etc) for further analysis. The program also has the facility to produce running averages of monthly combinations of data for successive periods of up to 6 months.

Deseasonalization of the initial time series can be performed by subtracting the overall monthly average from the relevant individual monthly values. The trend in any time series can be removed by fitting a standard regression model and taking the residuals as a new time series. It is also possible to select particular subsets of years and perform separate analysis on the corresponding time series.

A very powerful feature of the program is the ability to cross-correlate any two variables under analysis. Such cross-correlations can be performed either on data recorded at coincident time intervals or data lagged at any time interval from 1 to 24. Correlograms are produced in graphical form.

Biometrics Division holds a meteorological database of all the major weather variables recorded on a daily basis at Aldergrove Station since 1970. Meteorological data is included in the analysis of the abattoir pathology variables. The combined effects of several weather variables are analysed using standard mathematical transformations. Monthly averages of these variables can be analysed by the program as a time series and cross-correlated with any other weather or abattoir pathology time series variable. Furthermore, years can be categorised with regard to individual or combined weather variables and the mean incidences of paired abattoir pathology variables contrasted using standard statistical techniques. An example of a combined weather variable is "rain chill" (RC) which is calculated from the following;

$$RC = wh\,(35 - t)\,r$$

where w = wind speed knots
h = relative humidity percentage %
t = air temperature °C
r = rainfall mm

This is a modification to include rainfall from an equation developed by Steadman (1984).

An additional feature of the system is the ability to integrate the abattoir pathology database with a database containing information on the cost of carcase parts and the estimated cost of a specific disease syndrome to optimal animal production.

RESULTS AND DISCUSSION

The importance of abattoir pathology data as an effective method of disease surveillance in a population has been recognised in Northern Ireland for many years. Thus Gracey (1960), reporting on the disease incidence during the mid-50's in 600 randomly selected farms, considered concurrent abattoir pathology data essential to obtain an accurate assessment of the disease prevalence in the overall population. This extensive survey, which was one of the first to be conducted in any country, was initiated and administered at the Veterinary Research Laboratories (VRL) at Stormont. The VRL recognised the need to utilise the best computing technology, epidemiological and statistical expertise available in the proper construction of the survey and the subsequent analysis of the data.

Abattoir pathology data has been used in many countries to evaluate the epidemiological aspects of animal diseases. Most surveys have been conducted on an ad hoc basis on specific disease syndromes (Penny and Mullen, 1975 and Flesja et al, 1978). More recently, routine analysis of a dynamic database of abattoir pathology data has been performed in Sweden and Denmark. The Swedish system has been used in veterinary preventive medicine programmmes and in epidemiological investigations. However, the abattoir pathology data is restricted to pigs and available only from a single abattoir (Backstrom and Bremer, 1978). The Danish system is again restricted to pigs but collates data from the majority of abattoirs involved in the slaughtering of pigs in Denmark (Willeberg, 1980). This system has also been used in veterinary preventive medicine programmes and epidemiological investigations and also has the ability to monitor the disease status of individual farms presenting animals for slaughter.

The availability of monthly summaries of abattoir pathology data for all cattle, sheep and pigs slaughtered in Northern Ireland over a ten year period has enabled the formation of a large dynamic database for meaningful analysis. The special features of the software described in the previous section enables advanced time series analysis of abattoir pathology variables, their cross-correlation with the meteorological database and their integration with the economic database. The presence of 120 data points for each variable requires that great caution is exercised when analysing a particular time series. Significant cross-correlation coefficients, which are actually spurious, can arise when comparing two such time series (Jenkins and Watts, 1968). Thus, it is a prerequisite that, if significant seasonal effects and trends are detected, deseasonalization and detrending is carried out on each individual time series before cross-correlation takes place. Furthermore, as primary data analysis involves a considerable amount of exploratory research, especially with regard to the practical significance of different time lags, a very large number of cross-correlations must be investigated. It was thus considered essential to create a flexible, interactive program to perform such transformations and analysis on a routine basis.

Basic time series analysis of the abattoir pathology data is carried out before any cross-correlations are investigated. Thus, trends and seasonality patterns are produced and provide important epidemiological information about a disease. The recorded incidence of Cysticercus bovis in all cattle slaughtered since 1976 is demonstrated in Figure 1. C. bovis is the larval stage of the human tapeworm Taenia saginata. The clear downward trend in the incidence of this important zoonotic disease is very highly significant ($p<0.001$). The regression equation is $y = 1.55 - 0.15\ x$. The standard error of the regression coefficient is 0.01 while the proportion of variation (R^2) accounted for is 90%. The demonstration of a constant, significant decline in the incidence of C. bovis in cattle indicates that certain epidemiological determinants necessary in the occurrence of the disease are being controlled. Preliminary investigations would indicate that there has been a general reduction in the amount of untreated human sewage contaminating pastures and rivers due to an increase in the capacity and number of sewage plants operating in Northern Ireland. Liaison meetings have been initiated with the local medical authorities with the objective of determining the incidence of T. saginata infection in humans over the corresponding time period.

The average monthly incidence of pig livers condemned due to cirrhosis is presented in Figure 2 and shows a distinct seasonality pattern. Such cirrhotic lesions are almost invariably associated with the migration of the larval stage of the economically important pig nematode Ascaris suum. The highest incidence of the disease is recorded in the late summer and early autumn. The rate of development of the infective larval stage, which takes place in the environment, is temperature dependent and occurs most rapidly during the summer months. The level of infection to which pigs are exposed can thus increase throughout the summer months. This is clearly reflected in the recorded incidence of cirrhotic livers seen in late summer and early autumn. The distinct seasonality pattern of this abattoir pathology variable will be used to stress the epidemiological factors associated with this economic condition and the necessary use of strategic control measures to the pig industry in Northern Ireland. Additional analysis of this abattoir pathology variable has shown a very highly significant ($p<0.001$) increase in the incidence of ascaris infection in pigs over the ten year period.

The ability to cross-correlate two time series variables with a time lag factor operating on one of the variables is important in the analysis of the data. For example, weather conditions prevailing at a particular time interval may precipitate the occurrence of pneumonia in sheep. The occurrence of pneumonic lesions in sheep at slaughter may reflect the occurrence of such a previous disease incident. This possibility became evident by examining the distinct seasonality pattern recorded in the level of condemnation of sheep lungs due to pleurisy and pneumonia (Fig. 3). The maximum incidence was recorded in the spring and the minimum incidence was recorded in the summer. A similar seasonality pattern was reported by Simmons and Cuthbertson (1985) in the incidence of pneumonic lesions of sheep slaughtered at a Scottish abattoir.

Significant correlations were found between the incidence of lungs condemned due to pleurisy and pneumonia and several lagged weather variables. Rain chill was averaged over all years for each month of the year as was the abattoir pathology variable, pleurisy and pneumonia. A correlogam was constructed by calculating correlation coefficients of

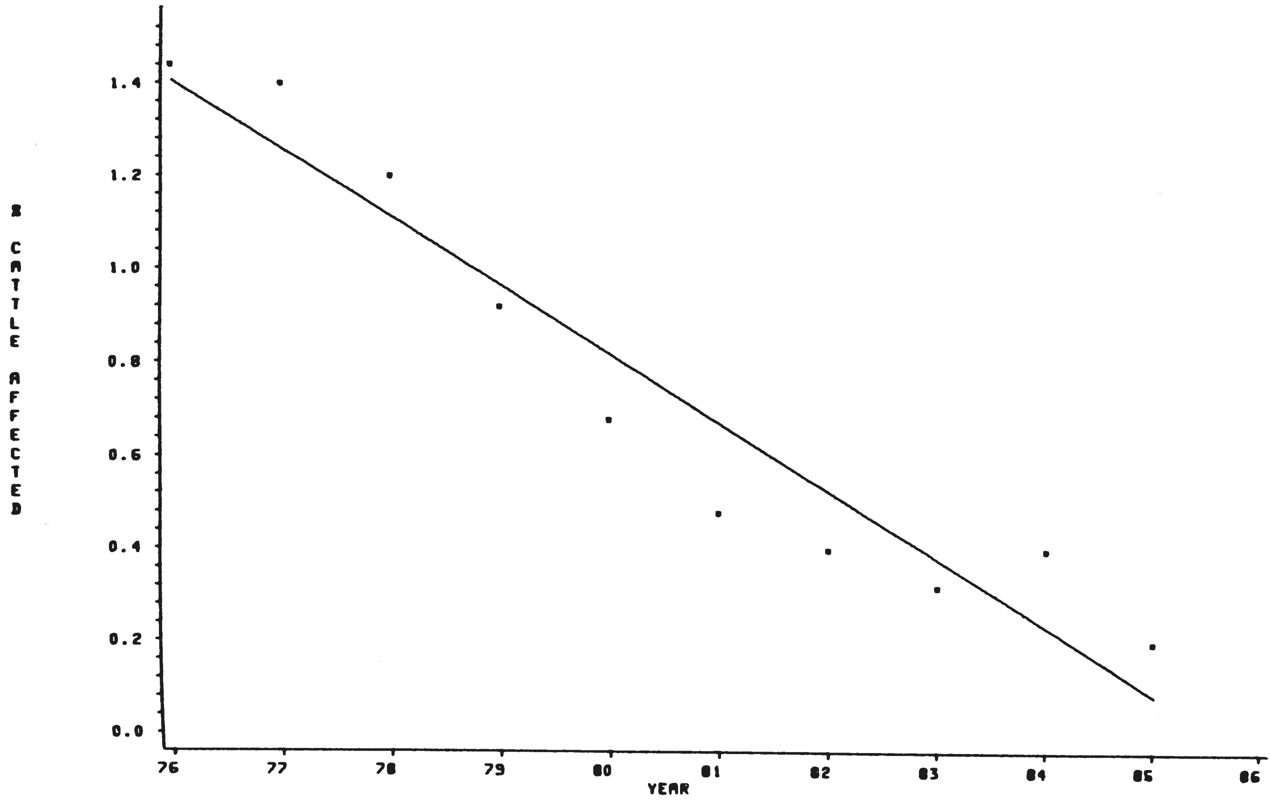

Fig. 1 The percentage incidence of <u>Cysticercus bovis</u> in bovine carcases from 1976 to 1985.

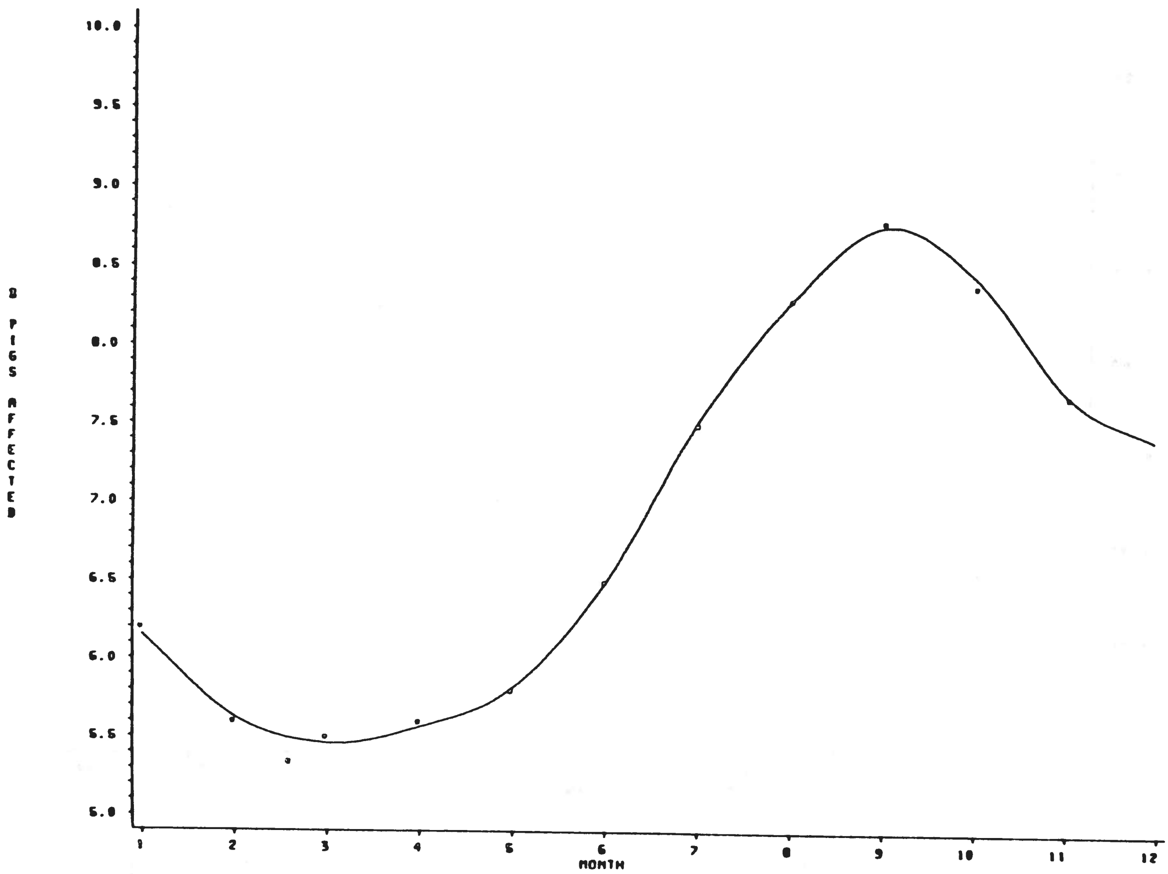

Fig. 2 The seasonality pattern of cirrhotic pig livers from 1976 to 1985.

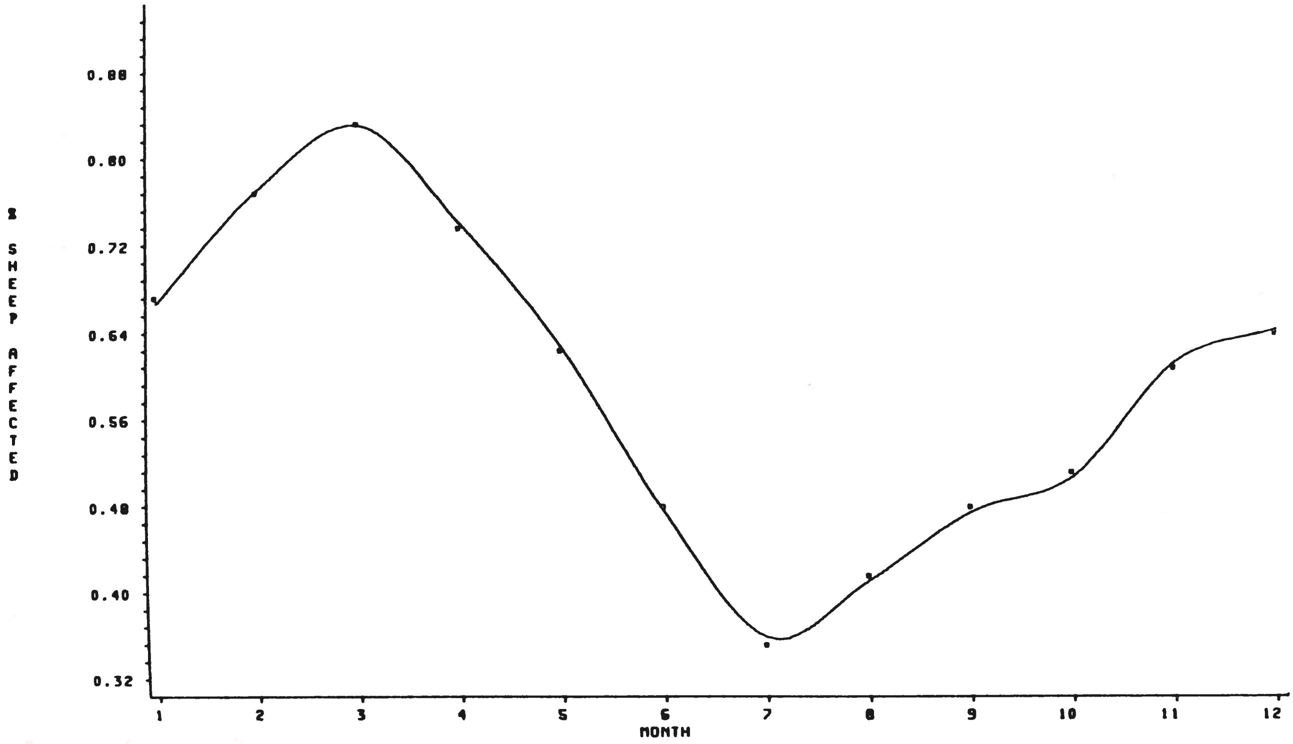

Fig. 3 The seasonality pattern of pleurisy and pneumonia in sheep from 1976 to 1985.

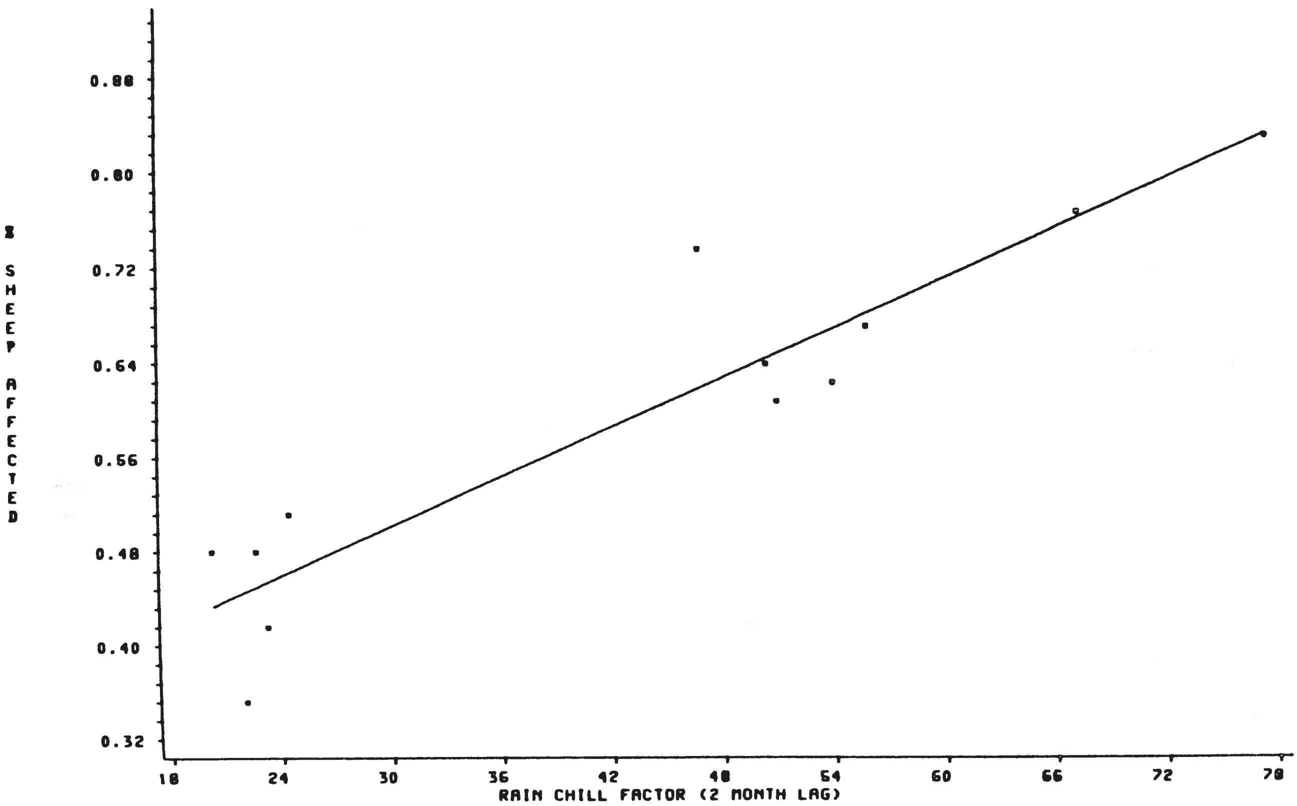

Fig. 4 The relationship between the average monthly incidence of pleurisy and pneumonia in sheep and the average monthly rain chill factor, lagged at a two monthly interval.

average monthly values of the abattoir and meteorological variables, the latter lagged from one to twelve months. A very highly significant correlation of 0.9 ($p<0.001$) was found at a lag of two months.

Assuming a dependency relationship between pneumonic lesions (y) and rain chill (x), a regression analysis was performed. The equation obtained was $y = 0.29 + 0.007 x$. The standard error of the regression equation was 0.0008. The relationship is shown in Figure 4 and demonstrates clearly that the prevalence of lung lesions in sheep increases significantly when the rain chill factor has been high two months previously. This is an extremely interesting observation of great practical importance to sheep production in Northern Ireland, an area with a high rain chill factor, especially during the winter months. Notably, the majority of the sheep population are not provided with shelter and this may increase their susceptibility to rain chill, possibly accounting for the strong correlation found between the two variables.

The ten years under current investigation were then further analysed by ranking them in ascending order depending on the mean value of annual rain chill. The years were then further categorised into two groups, high and low rain chill. The monthly values of percentage pneumonic lesions for each group are shown in Fig. 5. The mean value of pneumonic lesions for the low rain chill group was 0.49% and the high rain chill group was 0.73%. The arcsine root transformation was applied to these percentages and a paired t-test used to compare the mean values for each group, with individual months taken as blocks. A very highly significant difference was found between the overall means of the two groups ($p<0.001$). The practical effect of a high rain chill being recorded in any year is to increase marketly the prevalence of pneumonic lesions by approximately 50%.

The ability to integrate the abattoir pathology data with an economic database is essential in the assessment of the actual cost of a particular disease to the agricultural industry in Northern Ireland. The recorded incidence alone of a disease may not reflect its impact on profitable animal production. Rather, the combined effect of both incidence and cost of a disease dictate its importance. When the economic impact of a disease in the population is defined, it is possible for the industry to assess critically the cost-effectiveness of the use of existing control measures. Furthermore, research institutes can make positive decisions regarding the cost benefit of research projects directed to a particular disease. When new drugs or vaccines become available for the control of a specific disease, monitoring of their cost-effectiveness is possible using the combined databases.

Estimating the total cost of a disease may be performed by considering the direct loss to the producer of a valuable carcase or part and the indirect loss due to the presence of the disease during the production period. A classical example is provided by fascioliasis in cattle and sheep. Thus, not only does the producer lose the valuable liver, but more importantly, such a condemnation reflects an unacceptable level of parasitism during the production period. Taylor (1983) estimated the cost of this condition in cattle and sheep in Northern Ireland during 1982 to be approximately £5,000,000. This figure took into consideration both the value of livers condemned and the expected loss of both milk and meat production.

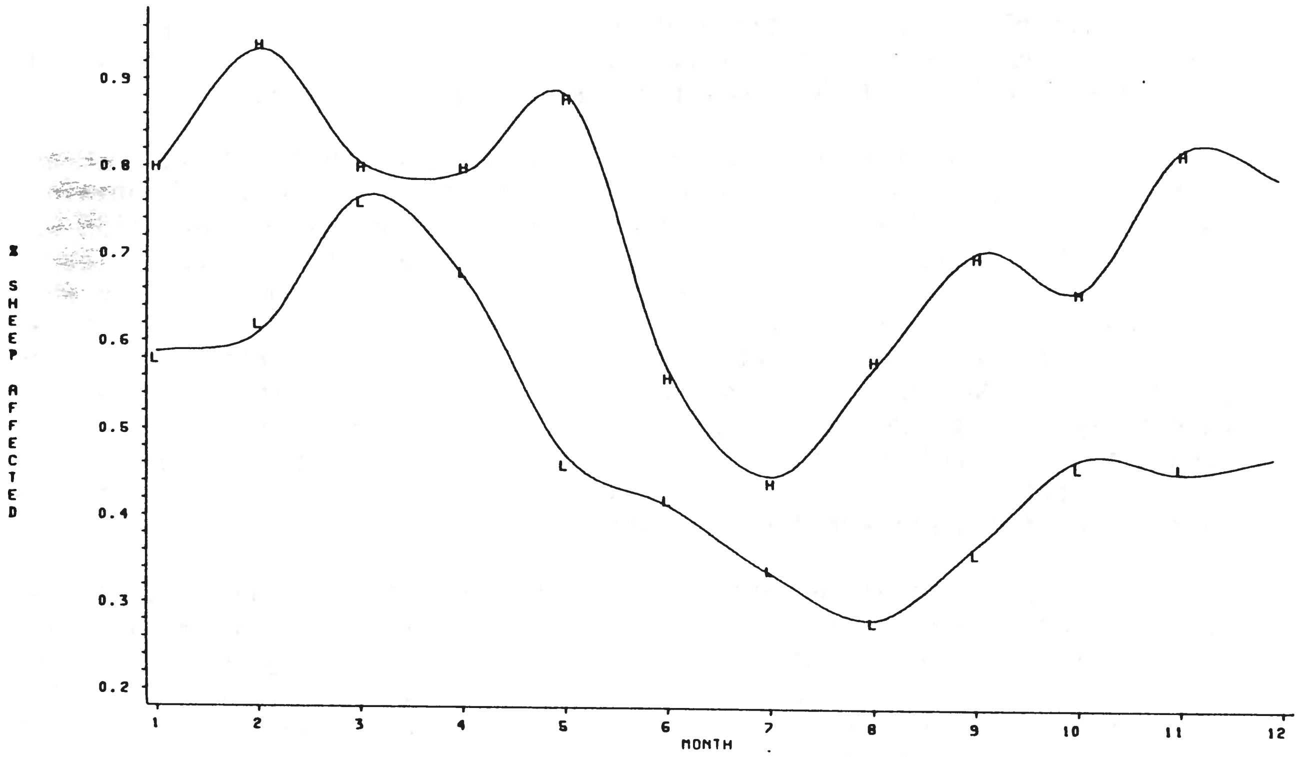

Fig. 5 A comparison between the average monthly incidence of pleurisy and pneumonia in sheep in high and low rain chill years.

The economic database is currently being constructed using the actual cost of specific carcases or parts since 1976. Production costs for each disease syndrome are also being added and take into consideration the actual cost incurred for each year. It is envisaged that a dynamic, interactive database can be created to assess accurately the cost of a disease using the most recent and authentic information available.

CONCLUSIONS

This computerised information retrieval system contains a large, dynamic database of abattoir pathology variables indicative of many, major production diseases. The entire population of the three major production species slaughtered in all abattoirs in Northern Ireland is being monitored on an ongoing basis.

The specially written software enables systematic time series analysis of pathology variables and also their cross-correlation with meteorological data. The software also facilitates the investigation of complex epidemiological interactions and permits the accurate assessment of the cost of many disease syndromes to animal production in Northern Ireland. The system has now been established on a permanent basis and routine reports will be issued to all interested parties concerned with profitable animal production. This will enable the assessment of the cost effectiveness of any control method implemented.

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CYSTITIS AND PYELONEPHRITIS IN SOWS CAUSED BY CORYNEBACTERIUM SUIS : EPIDEMIOLOGICAL CONSIDERATIONS

J.E.T. JONES*

Cystitis and pyelonephritis caused by Corynebacterium suis were first described in 1957 by Soltys and Spratling in England. Since that time the disease has been recorded in many countries throughout the world. It can be a serious economic problem in individual herds but there is no evidence that it is of national significance in any country.

ANIMALS AFFECTED

The disease occurs in sows, principally within 1 to 3 weeks of mating, but it may occur at any time during the reproductive cycle, e.g. mid-pregnancy or after parturition. There are a few, somewhat equivocal reports of its occurrence in males, unmated females and in females which have been artificially inseminated. There is no evidence that sows of a particular parity are especially susceptible.

CLINICAL AND PATHOLOGICAL FEATURES

The most consistently observed clinical sign is haematuria; in some cases haematuria may not be evident but the urine is turbid and may contain flecks of fibrin or pus. In severe cases there are signs of inappetence, thirst and loss of weight.

Pathological changes are confined to the urinary tract. Cystitis may be manifested by a catarrhal, hyperaemic, haemorrhagic, purulent, fibrinous or necrotic reaction in the mucosa of the bladder. There may be a unilateral or bilateral ureteritis and pyelonephritis. The ureters may be dilated and thick-walled with mucosal changes similar to those in the bladder. The pelvis of affected kidneys may be distended with foul-smelling fluid containing pus or blood or both. When pyelonephritis is at an advanced stage, yellow bands of necrotic tissue extend from the renal medulla into the cortex. These bands may coalesce to form diffuse yellow areas of varying size, commonly at the poles of the kidneys.

CORYNEBACTERIUM SUIS : CHARACTERISTICS AND HABITAT

Corynebacterium suis is a Gram-positive pleomorphic rod which tends to be larger in tissues than in cultures. It grows well on blood agar under

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anaerobic conditions, colonies attaining a diameter of 2-3 mm after about 3 days incubation at 37°C; there is no haemolysis. Although C. suis is frequently described as an anaerobe, it is capable of growing aerobically. It is relatively inactive when subjected to conventional biochemical tests.

The taxonomic position of C. suis has not been firmly established; it seems to have been assigned to the genus Corynebacterium largely on morphological criteria and because of its superficial resemblance to C. renale, an organism causing cystitis and pyelonephritis in cattle and other ruminants. Some workers consider it belongs to the genus Eubacterium.

Current information suggests that the principal habitat of C. suis is the preputial diverticulum of the boar. Only rarely is it found in the vagina of healthy females but it may be that existing cultural techniques are insufficiently sensitive to detect it there. There are no reports of the isolation of C. suis from any anatomical site in the pig other than the urogenital tract nor has it been isolated from any other animal. The organism may be isolated from the floor of pens housing male pigs but we have not been able to demonstrate its presence in soil, faeces, foodstuffs or unused bedding materials.

EPIDEMIOLOGICAL STUDIES

The carriage of C. suis in male pigs

In a preliminary investigation (Jones, 1978) it was shown that 75.0% of adult male pigs harboured the organism in the preputial diverticulum and since this structure is the main habitat of C. suis it is appropriate to describe it briefly.

The diverticulum is a bilobed sac situated in the anterior part of the prepuce and dorsal to it. The sac is lined by keratinised stratified squamous epithelium but has no glandular elements. In adult boars the sac has a capacity of 100-150 ml. It contains a foul-smelling ammoniacal fluid having a pH of 8.5-9.0, rich in a diversity of bacteria including large numbers of C. suis ($10^5/10^7$/ml). The functions of the sac and of the fluid it contains are unknown but the fluid is often expelled during coitus.

In a series of investigations (Jones & Dagnall, 1984) it has been shown that C. suis is present in the diverticulum of a high proportion of pigs over the age of 4 months (Tables 1 and 2).

Observations in individual herds have shown that the carriage of the organism by male pigs is influenced by the system of husbandry employed. We investigated three commercial herds (A, B and C) in which the systems of management of young pigs differed.

In herd A, pigs were weaned at 5 weeks of age and were housed either in the pen in which they had been born or as individual litters in a weaner house. When they were 8 weeks old they were moved to a fattening house accommodating about 5000 pigs aged 8-20 weeks; in this house pens were constructed of tubular steel so that there was close contact between pigs and there was ample opportunity for the spread of urine and faeces between adjacent pens. In the age group 5-8 weeks, 26 pigs originating from 7 separately housed litters were examined. C. suis was not isolated from any of them. However, in the age group 9-15 weeks, C. suis was isolated from 49 (77%) of 64 pigs in the fattening house.

Table 1. The isolation of Corynebacterium suis from the preputial diverticulum of adult male pigs in various regions of the United Kingdom

Region	Number of pigs examined	Number from which C. suis was isolated
Eastern (9)*	115	103 (90%)
South Eastern (4)	22	20 (91%)
South Western (1)	3	2 (67%)
East Midlands (3)	30	28 (93%)
West Midlands (3)	17	14 (82%)
East Scotland (2)	11	11 (100%)
North Scotland (1)	7	5 (71%)
North Wales (1)	15	10 (67%)
Northern Ireland (1)	4	3 (75%)
Total (25)	224	200 (89%)

*Figures in parentheses indicate number of pig units sampled in each region.

Table 2. The isolation of Corynebacterium suis from the preputial diverticulum of slaughtered male pigs, aged 4-6 months, originating from six herds

Number of pigs examined in each of six different herds	Number from which C. suis was isolated
10	10
10	9
15	15
10	10
17*	16
7	6
69	66 (96%)

*Castrates

In herd B, pigs remained in the pens in which they had been born until they were sold at 20 weeks of age. They were weaned at 5 weeks. Eight of 9 boars in this herd harboured C. suis in the diverticulum but were not in contact with the young pigs. Thirty-six pigs aged 5-17 weeks, distributed among 8 litters, were sampled on two occasions separated by an interval of 5 weeks. C. suis was isolated from one pig on one occasion only.

Herd C was quite unusual. It consisted of 100 sows and their progeny. This herd had been established from one artificially inseminated gilt. All pigs in the herd had been derived from the inseminated female progeny of this gilt. There were no adult boars in the herd. The preputial fluid of 26 pigs, aged 4 months, was sampled but C. suis was not isolated from any.

The colonisation of the preputial diverticulum by C. suis

As it has been shown that in many herds a high proportion of older pigs harboured C. suis in the diverticulum, it was decided to sample very young pigs to determine the age at which the diverticulum becomes colonised. Two College herds were available for this investigation; one was a herd of Large White (LW) pigs and the other was one of Göttingen miniature pigs (GM).

In the LW herd 38 male pigs distributed among 7 litters and in the GM herd 29 pigs in 10 litters were sampled at 5 day intervals from birth to 35 days. In the LW herd, colonisation was demonstrated in 5 pigs among 2 litters at 28 days of age and in all pigs in all litters at 35 days. In the GM herd, one pig in one litter was colonised at 5 days; thereafter, colonisation occurred in an increasing number of pigs and litters until at 35 days, C. suis was present in every male pig in every litter. Vaginal samples were examined from all female pigs in all litters (27 LW, 26 GM) at the same time as the male pigs were sampled. C. suis was not isolated from any of them.

Transmission of C. suis infection between male pigs

Experiments on transmission were conducted in pigs, aged 8-10 weeks derived from Herd B and known not to harbour C. suis in the diverticulum. The results of these experiments have been recorded elsewhere (Jones & Dagnall, 1984). It was shown, in three of four experiments, that following the inoculation of C. suis into the diverticulum of one of a group of pigs, the others become infected within 7 days; in a fourth experiment in-contact pigs became infected within 2 weeks. It was clear that transmission took place readily.

The carriage of C. suis in female pigs

During the course of our work on C. suis we have sampled the vaginal (vestibular) mucosa of many female pigs of various ages. We have found the organism at this site very infrequently; for example, in one survey of the vaginal flora of pigs we isolated C. suis in 1/22 aged 5-10 weeks, 1/10 aged 15 weeks, and in 0/80 sows.

The transmission of C. suis from boars to sows

In one of our investigations (Lastra & Chappell, unpublished) the vagina (vestibule) of 83 sows was sampled immediately before mating. C. suis was not detected. Five minutes after being mated with boars known to harbour C. suis in the diverticulum, the organism was detected in the vagina of each of 22 (26.5%) sows. Two hours later C. suis was isolated from only one of these sows.

DISCUSSION

The results of our investigations show that C. suis is present in the preputial diverticulum of most male pigs over 4 months of age and that it is rarely present in the vagina of pigs of any age.

The age at which young males become colonised by C. suis is influenced greatly by the degree of contact they have with older pigs and this, in turn, is governed by the system of husbandry practised in individual herds. When young male pigs are maintained in isolation they rarely become infected with C. suis but if they are in close contact with older pigs they become infected readily. The commonest source of infection is probably the floor of pens contaminated by preputial fluid which, in older pigs is a rich source of C. suis. Transmission experiments clearly show the ease with which C. suis may spread from infected to uninfected pigs. In the commonly practised husbandry systems prevention of transmission would be an impracticable task.

C. suis may be transmitted from boars to sows at the time of mating and if it becomes established in the urogenital tract of sows, cystitis and pyelonephritis may result. Culling of carrier boars has been suggested as a method of preventing infection of sows; this does not seem worthwhile because replacement boars will almost certainly be infected. Culling might be of value if there are 'pathogenic' and 'non pathogenic' strains of C. suis but we have no evidence that such different strains exist. Treatment of carrier boars by instillation of antibiotics into the diverticulum is in our experience, ineffective. Even if it was effective, boars would soon be reinfected. Currently, the only means of attempting prevention of the disease in sows is to administer antibiotics to sows immediately after service or, if outbreaks of the disease are economically serious, to use artificial insemination.

As with so many infectious diseases, we urgently need information on the factors that predispose the host to disease. The elucidation of factors which permit the conversion of infection to disease is one of the greatest challenges facing veterinary epidemiologists.

ACKNOWLEDGEMENTS

Table 1 and 2 are reproduced from the Journal of Hygiene by permission of Cambridge University Press.

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ASSESSING THE POLICY OF BADGER CONTROL AND ITS EFFECTS ON THE INCIDENCE OF BOVINE TUBERCULOSIS

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National programmes for the control of disease in farm livestock can be said to hinge on three issues - preference, possibility and price. That is to say, no scheme can be implemented without first confronting the questions (a) Do we want to do it? (b) Can it be done? (c) Is it worth doing? Only then do questions arise as to exactly how control should be undertaken and the extent to which it should be continued.

It is worth highlighting this point. Otherwise it may be presumed too readily that something should be done about some disease condition just because by definition it is undesirable and there exists a technical means of controlling it. The range of groups who can claim a valid interest in the decision is in reality quite wide. The veterinary profession may take the lead, but they are just one of the interest groups - albeit the only one qualified to address the second of the three questions posed above. The first question, concerning desirability, is more a matter for society at large and especially for all those who may feel affected, directly or indirectly, by the measures taken. The third question whether control is worthwhile involves the skills and analytical techniques of other distinct professional groups. All this merely emphasises the obvious point that animal disease control programmes have political and economic dimensions that are no less important than their veterinary aspects.

BOVINE TUBERCULOSIS AND BADGERS

Bovine tuberculosis is a good case in point. As a debilitating human affliction and widespread cattle disease in the UK 50 years ago, there was obviously a strong social preference to reduce its incidence as far as practicable. The possibility of doing so existed in the ability to test live cattle for the presence of the causal organism, Mycobacterium bovis, and the subsequent slaughter of all reactor animals. The procedures were relatively simple and inexpensive, and a national eradication programme was justified on the grounds of all three criteria.

Such a programme got going in earnest in 1950 and was highly effective. The continual removal of infected individuals from herds brought a dramatic decline in the incidence of tuberculosis in the cattle population, from a reported 40 per cent in 1934 to well under one per cent of herds having reactors in 1965. For some years now the situation has been one in which the disease no longer exists in the domestic cattle population, but occurrences ("herd breakdowns") are experienced as a result of introduction from outside sources.

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In 1971 it was demonstrated conclusively that one such source is the wild badger, and it is now evident that in some localities 10-15 per cent of the badger population are infected with M. bovis. These localities lie almost exclusively in South West England, and the existence of a significant wildlife reservoir of tuberculosis in a major region for dairy and beef cattle production has put a considerable brake on the national programme to eradicate the disease. This regional specificity has not been adequately explained, nor has the non-uniformity of the problem of badgers and bovine tuberculosis within the region. Nevertheless, taking the seven counties (Cornwall, Devon, Dorset, Somerset, Avon, Gloucester and Wiltshire) to constitute "the South West", the average incidence of reactor herds in this region since 1970 has remained ten times higher than in the rest of England & Wales.

Clearly tuberculosis eradication was severely hampered while revealed infection was being removed from only one of two contiguous affected populations. Consequently, since 1975 control efforts have been directed at the main wildlife reservoir of the disease. The Ministry of Agriculture, Fisheries and Food has operated a policy of eliminating all badgers in the area surrounding a farm upon which a tuberculosis breakdown has occurred if that breakdown can be attributed to infection in badgers. In addition, removal operations have taken place if the presence of known infected badgers was considered to constitute a risk to the health of local cattle. The procedures and precise conditions under which badger removal has been undertaken are complex and varied, and are detailed elsewhere (e.g. Dunnet, Jones & McInerney, 1986). Some 250 control operations have taken place, primarily in four specified "Control Areas" in South West England - although in recent years operations have extended to sites in Dyfed (1981), Staffordshire (1982), Cumbria (1983) and East Sussex (1984). The success of those operations in contributing materially to the reduction of breakdowns in cattle herds has been a matter of some dispute between different interested parties, and two major reviews of the policy have been undertaken (Zuckerman, 1980 and Dunnet et al, 1986). This paper discusses some of the issues involved in attempting to draw any reliable conclusions as a basis for policy action.

ASSESSING THE TECHNICAL SUCCESS OF BADGER REMOVAL

The period for analysis commences in 1963. By this time the dramatic decline in the number of reactor herds nationally had begun to tail off, and the eradication scheme had reduced the overall level of incidence to tolerably low levels. From this time onwards, however, the divergence between the situation in the South West and in the rest of the country was increasingly apparent. The data series ends in 1985, the last year for which full information is available. The task then is to explain the observed time series in herd breakdowns in the South West region, where badger control was undertaken, as compared to the rest of England & Wales where it was not.

One immediate problem is that, since MAFF did not deliberately refrain from badger removal in any potentially affected locality, there are no observations to serve as a "control treatment" in the experimental sense. Contrasting trends in the South West with those in the rest of the country serves only superficially as a comparison of the effects of badger removal, since the two regions are not comparable in all other respects. In particular, there was a far lower density of cattle, a lower incidence of herd breakdowns, and no real badger problem in the country outside the South West. Consequently, conclusions drawn from the South West data must rest upon some assumption as to the likely level of breakdowns if there had been no badger policy.

The relevant data are shown graphically in Figure 1.

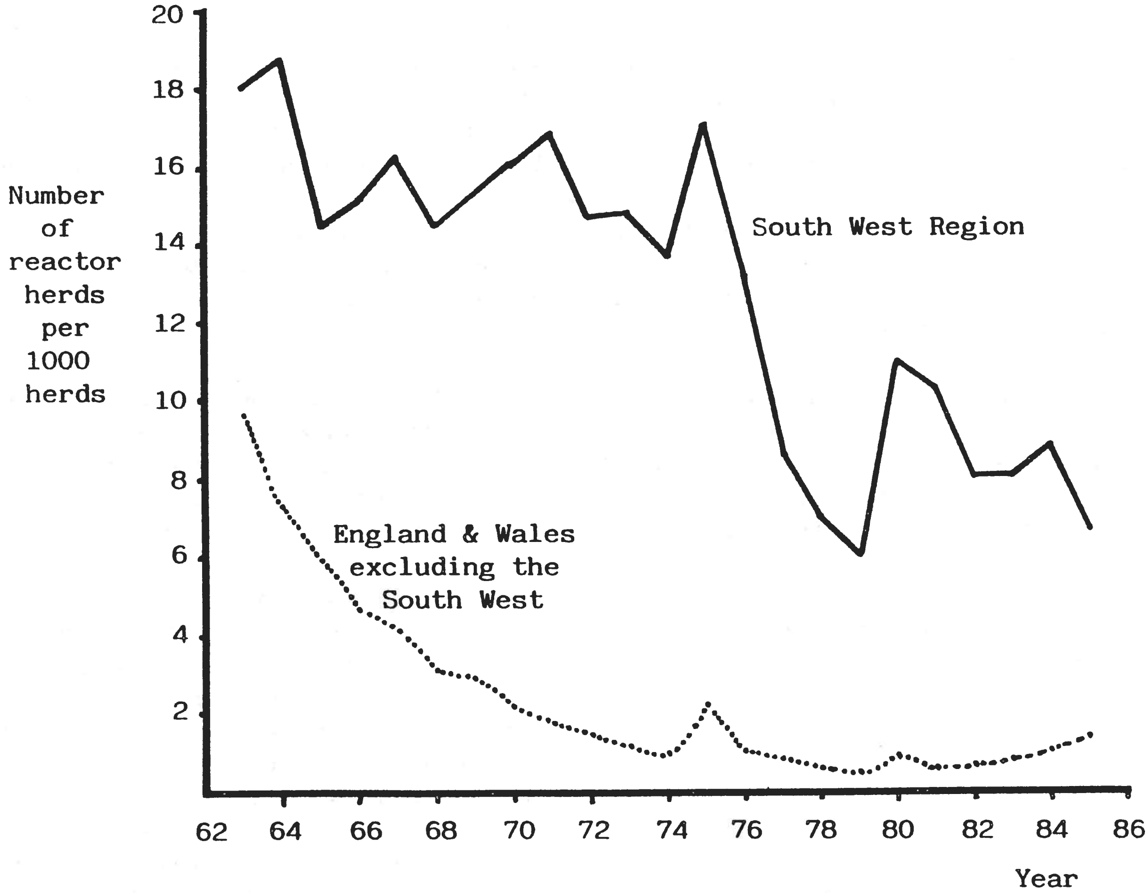

Fig. 1 Incidence of reactor herds by region, 1963-1985

The situation is characterised in terms of reactor herds, rather than reactor cattle, because the policy of herd testing and culling reactors works primarily on reducing the transmission of tuberculosis from herd to herd. The emergence of the disease within a herd, then, is the event which marks a breakdown - and hence is a measure of non-success - regardless of the number of animals affected. Once infection has entered the herd, the potentially easier transmission between animals means that it is largely incidental (and primarily dependent on the time lapse before a test is undertaken) how many individual reactors there are. Further, the proportion of reactor herds rather than the absolute number is taken as the indicator, since the general decline in the number of cattle herds (down by about one third over the period) will itself account for a reduction in breakdown incidents.

Figure 1 shows that in England & Wales outside the South West there has been a consistent exponential rate of decline in the incidence of herd breakdowns over the period 1963-1985. This pattern is broken only by a noticeable discontinuity in the mid 1970's, with some hint of a possible rise since 1981. By contrast, the picture in the South West is much more variable and the overall trend less easily discerned. The greater year-to-year variability is not surprising, for the annual incidence in the rest of the country is smoothed by a smaller absolute number of breakdowns being related to a far larger number of herds. However, it is the underlying trends in the rate of breakdowns that are the major focus for explanation.

It is useful to set out the chronology of events that lie behind the South West data. From 1963-1975 herd breakdowns were treated no differently from those in the rest of the country. Then in September 1975 the programme of removing badgers by gassing their setts was instituted in the specified Control Areas. This continued until September 1979 when it was suspended while Lord Zuckerman undertook his review of the policy. Gassing recommenced in November 1980 but ceased finally in June 1982 when experimental evidence suggested it was insufficiently humane. It was replaced in August 1982 by procedures of live trapping and subsequent shooting, which have continued until the present time.

Even the most determinedly scientific eye often cannot avoid seeing what its owner prefers to find in a collection of information. Thus it is that various parties have looked at the South West data series and drawn different conclusions about what it reveals. As long as each of these explanations has some plausible basis, to the empiricist they are merely alternative testable hypotheses. Unless there is convincing accessory evidence forcing one to accept one hypothesis and reject the others, the only way to discriminate between them is via the more neutral method of statistical testing. Lacking the insights possessed by those more closely involved, and hence unhampered by disposition towards a preferred explanation, the author has simply addressed the question "Which plausible statistical model best fits the observed data series?" Attempts were made to answer this question by fitting regression models reflecting different presumptions about the causal structure underlying the time path of herd breakdowns observed in the two broadly defined regions of the country. The different models, and the hypotheses they imply about the effect of badger removal on the annual incidence of reactor herds in the South West, are set out below. The regression lines associated with each hypothesis are drawn in Figure 2 over the graph of the observed values.

Hypothesis A: Badger removal operations have had no observable effect, and there is no fundamental difference in the data series before and after 1975. The period 1963-1985 is best described, therefore, by a single regression line showing constant parameter values with no breaks in its structure.

Hypothesis B: The incidence of herd breakdowns was approximately constant prior to 1975, and badger removal has been successful in progressively lowering that level. Thus, there is a distinct break in the series at 1975, after which date there has been a significant downward trend in incidence.

Hypothesis C: Badger removal has had no significant effect on herd breakdowns, which have remained largely constant over the whole period except for a distinct once-and-for-all decline in the mid-1970's. This can be associated with two factors. One was the restriction of imports of untested live cattle from Ireland in 1976. (Infected Irish cattle were the source of over half of all herd breakdowns in England & Wales from 1972-76 but the proportion then fell markedly and accounts now for less than 10 per cent.) However, this factor was never important in the South West, where Irish store

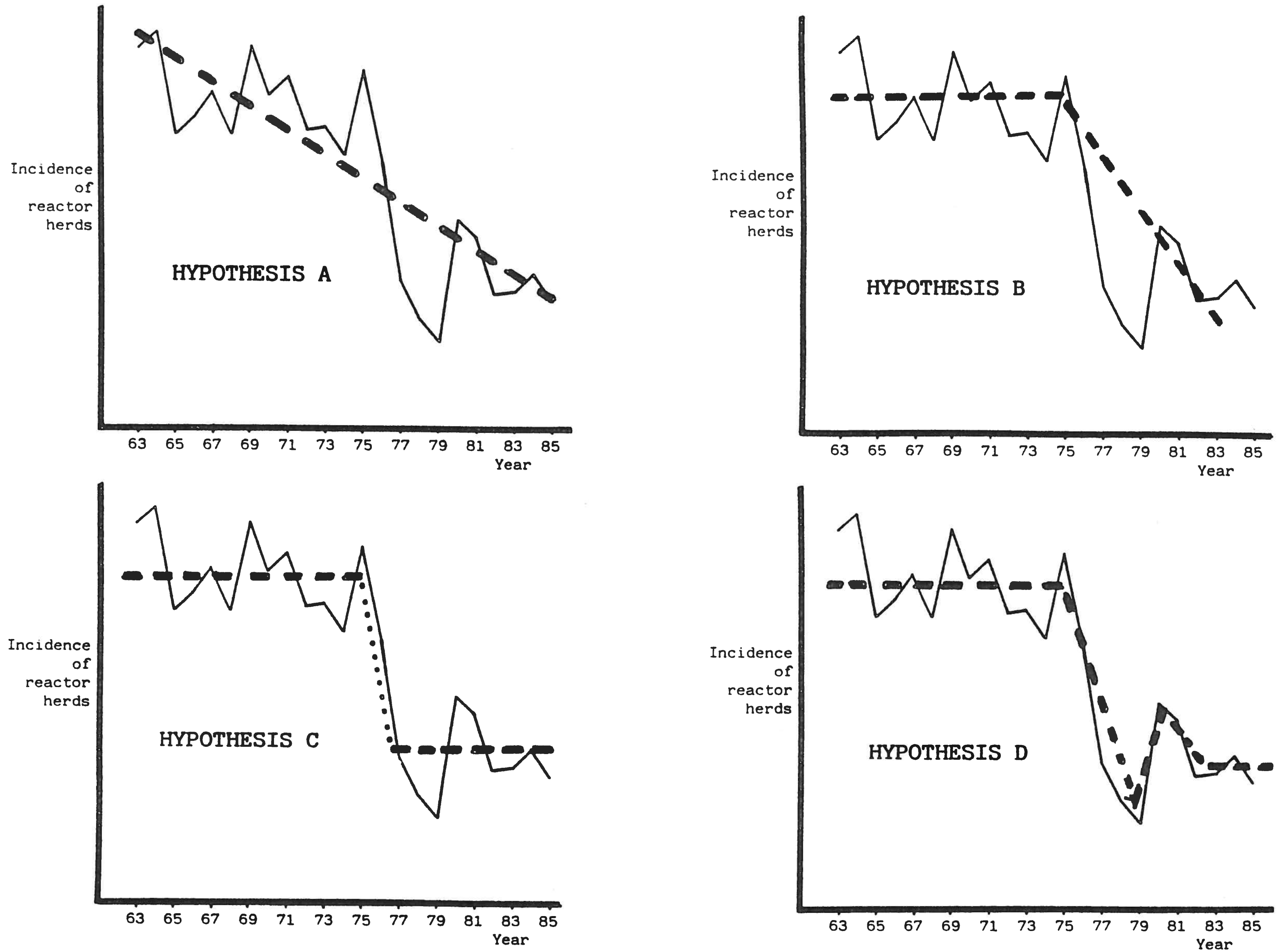

Fig. 2 Alternative hypotheses for explaining the pattern of herd breakdowns in the South West, 1963–1985

cattle are only rarely brought in. A second potentially important influence was the change in the comparative tuberculin test in March 1975 from the use of Weybridge human purified protein derivative (PPD) to Weybridge bovine PPD. The effect of this was to make the test more reliable in that it reduced the number of "false positive" results - i.e. herds identified as having reactors but which were not later confirmed by post-mortem examination or laboratory culture.

Hypothesis D: Prior to 1975 herd breakdowns occurred at an approximately constant rate, which declined progressively after the introduction of the badger control policy. The level rose in 1979-80 while operations were suspended during the Zuckerman review, declined again with the resumption of gassing, but then levelled up with the move to live trapping which is a less complete method of eliminating infected badgers. Such a hypothesis seems plausible, and those who believe badger control is effective can see the data as entirely consistent with it. However, it is much too precise to allow statistical testing as it deals with a succession of short period effects for which annual data provide few observations. It is mentioned here for completeness, but is not analysed further.

By extending the trend observed prior to 1975, each of these models predicts an expected time path of breakdowns in the absence of badger control, thus offering a basis for measuring the extent to which the policy has been successful.

Statistical results

For each of the above hypotheses a regression model having the following general form was fitted

$$I_T = a + D_a + bT + D_bT$$

where I_T = incidence of herd breakdowns in year T

T = 1963, 1964,....1985

The dummy variables D_a and D_b are employed to test for the structural shifts in intercept and slope embodied in Hypotheses B and C. D_b is designed to capture the expected steeper decline in incidence after badger control commenced, and so takes the value of 0 for years 1963-74, and 1 for the years 1975-1985. D_a is an intercept-shift variable to reflect the step-drop in incidence advanced in Hypothesis C. Alternative formulations were employed to allow this effect to be spread over two years and occurring in either 1975/76 or 1976/77.

Analyses were conducted separately on the data series for the South West region and England & Wales excluding the South West. For convenience these regions are referred to henceforth as SW and EW respectively. The models were fitted in both linear and non-linear form, the latter using logarithmic transformations. The results from the best fit models are shown in Table 1.

For EW it is the logarithmic model, reflecting a progressive slowing of the rate at which breakdowns declined, which fits the data best and the trend coefficient is highly significant. The dummy variables suggest a marked drop in incidence around 1976/77 (D_a negative) and a reduced rate of decline thereafter (D_b positive). The statistical significance of these variables is a little weaker than the conventional 5 per cent level but overall the explanation seems quite convincing.

Table 1. Best fit regression lines

	Intercept a	Intercept shift D_a	Time trend b	Trend shift D_b	$\bar{R}^2$	D.W.
England & Wales excluding South West (logarithmic model)	3.97 (6.59)	-1.05 (-1.82)	-1.04 (5.51)	0.241 (1.51)	.859	1.03
South West (linear model)						
Hypothesis A	19.0 (20.09)		-0.504 (-7.32)		.719	1.22
Hypothesis B	16.8 (16.38)		-0.121 (-0.93)	-0.302 (3.27)	.816	1.68
Hypothesis C	16.7 (19.03)	-6.25 (-2.36)	-0.098 (-0.92)	-0.009 (-0.07)	.843	1.94
	16.8 (20.38)	-6.4 (-4.65)	-0.099 (-1.00)		.851	1.94

Intercept shift over 1976/77. Figures in parentheses are t values.

For the SW region Hypothesis A, which presumes a declining disease incidence independent of badger control, has rather weak consistency with the data. The simple linear model does show a statistically significant downward trend, not surprisingly, but its explanatory power is less than for other models. Hypothesis B gives a better fit, showing a slight but non-significant fall in incidence initially but then a convincing rate of decline after badger removal was introduced. This is fully consistent with one set of prior expectations. However, in a purely statistical sense the observed pattern of herd breakdowns is best explained by Hypothesis C, which finds no significant time trends but a clear shift in intercept. Its simplest interpretation is that badger control in the SW has had no effect. The generally lower level of incidence in recent years compared to pre-1975 is attributed largely to a single step reduction in the mid-1970's, and that is inconsistent with a pattern of progressive decline that would be expected if badger control had been effective in reducing the risk of herd breakdown. It remains uncertain how to account for the observed drop, but the existence of a similar discontinuity in the EW series does suggest some factor was at work nationally that had nothing to do with badger control. One is left to presume that the change in the tuberculin test, plus other unidentified influences, caused the break - although veterinary opinion tends to reject this explanation as insufficient. The only other analysis to have addressed this issue (Wilesmith, 1986) concluded there was no evidence that the changed test could have accounted for the decline in herd breakdowns observed in the particular local areas that had been subject to badger gassing.

Logically, of course, badger control **must** have had some effect if the badger population really is a source of tuberculosis. Removing infected (and non-infected) individuals inevitably lowered the risk they might at some time have transmitted the disease to cattle, and hence some breakdowns will have been averted. (Although there are those who argue that, because badgers live in well-defined social groups and show little geographic mobility, their removal **after** having caused a breakdown has no effect as a pre-emptive strike with respect to a possible future breakdown in a different herd). A further hypothesis, advanced by some veterinarians in MAFF, is relevant here but it cannot be tested because of the absence of affected areas not subjected to badger removal. The true underlying structure of herd breakdowns in the SW could have been on a progressively rising trend from the early 1970's because of the growing badger population and the increasing spread of tuberculosis within it (this is merely reasonable supposition; unfortunately there is no wildlife database sufficient to affirm it). The possible scenario is then as shown in Figure 3. The herd testing programme progressively reduces the incidence of the disease in cattle while independently the number of infected

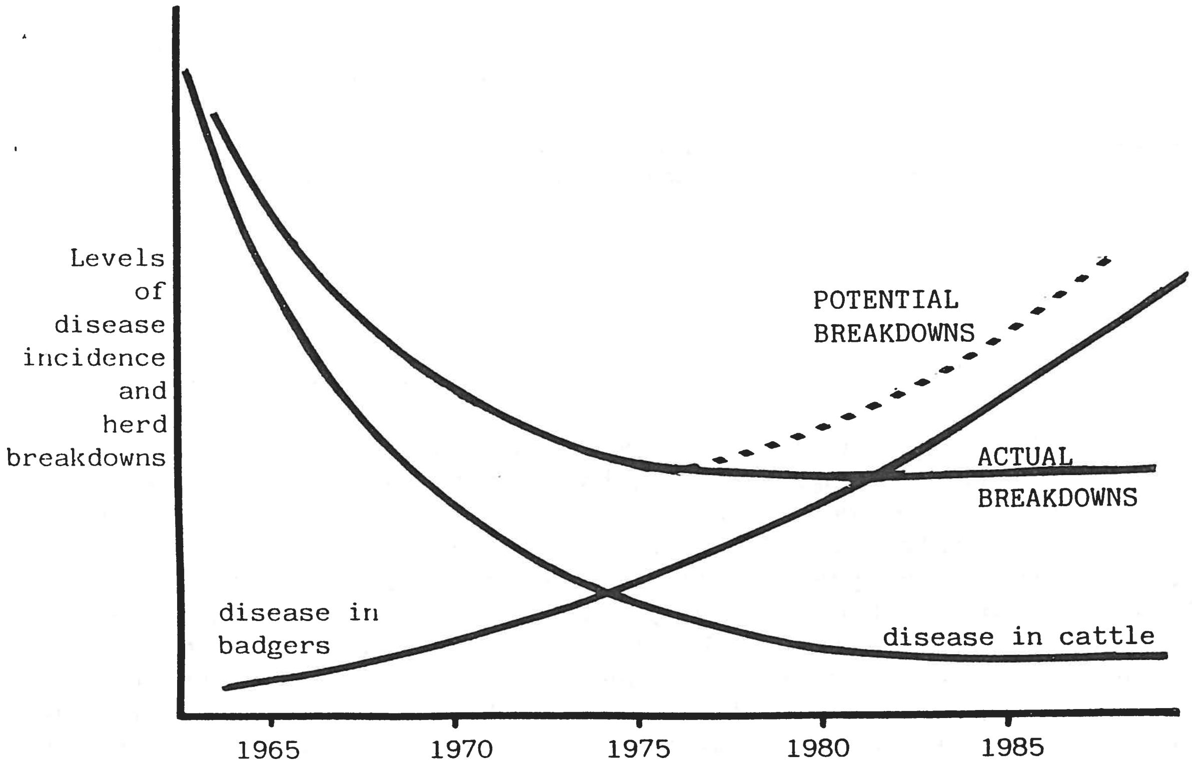

Fig. 3 Possible causal structure for herd breakdowns in the South West

badgers in the companion population increases systematically. The net effect is the incidence of herd breakdowns falls while the cattle control policy dominates events, but then rises from a floor level due to reinfection from the increasing badger population. If this minimum occurred in the mid-1970's then the introduction of badger removal could have been strikingly effective, and continues to be so as time goes by, in preventing an upsurge in breakdowns that would otherwise have been experienced.

This points up the essential dilemma of relying on "neutral" scientific analysis to underpin policy judgements and decision making. If the tested hypotheses are each technically plausible, and statistical analysis is an entirely neutral way of discriminating between them, then one has no alternative but to conclude that the data elects Hypothesis C as the "correct" explanation. But if other information or scientifically-based professional opinion suggests an alternative hypothesis ought logically to be accepted but cannot prove it, one has found no rational basis for choosing a course of action. When do we reject the "black box" solution, despite relying on it in other circumstances, because it seems not to be sufficiently convincing? When do we discount objective professional judgements on what the data show because they may have, unwittingly, become influenced by prior conceptions?

ASSESSING THE ECONOMIC SUCCESS OF BADGER CONTROL

Badger control involved a considerable expenditure of resources which could well have been used for other purposes. In principle, unless they brought benefits greater than obtainable in those other uses then they were misallocated. That may seem too doctrinaire, but certainly there should be some determination of whether benefits were sufficient relative to the costs incurred. In this case, benefits occur in the form of herd breakdowns that were avoided, and so some measurement is required of the extent by which breakdowns declined and the value attached to each.

The question "was it worth it?" introduces a secondary question "worth it to whom?", since there is no uniform group who carry all the costs and receive all the benefits. For example, the bulk of the measurable costs of badger removal are carried by MAFF, and therefore paid by taxpayers, while the measurable benefits accrue largely to that sub-set of cattle farmers who avoid the income loss associated with a breakdown. Consideration must also be given to elements of cost and benefit which are quite real but for which a monetary value cannot readily be assigned. Many of these accrue to people outside the agricultural system - such as benefits in terms of better human health, or the costs felt by those who object to the killing of healthy badgers. There is a tendency to think such elements of value are intangible, hence impossible to handle, hence unimportant, and to pass over them. A major thrust in modern Economics (as opposed to Accountancy) is directed towards bringing as many of these into consideration as possible, without pretending to make measurements and comparisons that are definitive and absolute.

An economic analysis of the badger control policy exemplifies these two facets of the typical economic evaluation. We first identify the balance of costs and benefits as perceived from two different standpoints - the farmer and the public purse - and then consider how the information on measured net benefits can be used to guide a decision on the overall worthwhileness of the policy.*

Evaluation at the private (farmer) level

Measurement of the gains and losses to the farmer is relatively straightforward, being captured largely in the financial receipts and outlays he experiences. We would expect the net effect of these to be substantially positive, since the costs of badger removal incurred by a farmer are minimal. The operations are conducted by Ministry staff who, apart from requiring the odd cup of tea and imposing some constraints on livestock movement in the locality of gassing/trapping, undertake all the necessary work. The benefits to farmers however are quite evident in the form of the losses they avoid

*Cost and benefit figures referred to in the following were determined in a detailed study undertaken by MAFF Economics (Resource Use) Division, as yet unpublished.

through suffering fewer breakdowns. The costs of a herd breakdown include the net loss on slaughtered reactor animals (which are compensated at only 75 per cent of their market price, and much less if the animal has high value as pedigree or breeding stock); reductions in output and margin through imposed restrictions on livestock sales during the period the farm is declared affected, and the labour costs and other disruption effects associated with re-testing of the herd. These have been estimated at 1983/84 prices to total on average some £2,505 for a confirmed breakdown, and significantly less (£445) if the disease is unconfirmed.

Farmers as a group, therefore, will be better off by some £500-£2,500 for every breakdown avoided through the badger control policy. Since they carry virtually none of the costs, they must judge it to have been worthwhile from their own private standpoint even if its effect on reducing breakdowns has been minimal.

Evaluation at the public (economy) level

Economic benefits: The benefits to the economy from badger control are still captured in the breakdowns averted, but the valuations placed on these may differ from those calculated for farmers. The essence of an economic (as opposed to a financial) assessment is to deal in terms of real resources, not just money. For example, the slaughter of reactors or dangerous contacts is not a straight loss to the economy unless the animal is scrapped completely. Output is probably reduced due to early termination, but the carcase yields a benefit in terms of meat for human (or animal) consumption which should be set against the value of the animal's "normal" output. The financial compensation paid to the farmer is independent of this, and is neither a cost nor a benefit to society; it is a "transfer payment", money transferred from the government's (taxpayer's) bank account to the farmer's. Furthermore, reductions in real output that result from a breakdown may not be valued appropriately by applying market prices. If those prices are administratively established (as in a price support policy) they may in no way reflect the true value to the economy. In the extreme case, if a commodity is already in surplus supply extra output brings no value to the economy at all (even though farmers receive money for it); the loss of that output therefore represents no real cost. Such considerations are valid obviously only at the margin, and not for the total output of the industry, but they are of crucial importance in assessing policies whose effects are identifiable as relatively small additional increases/decreases in output or resource use.

In addition to real output losses, the economic costs of a herd breakdown include the value of resources allocated by the public sector in undertaking post-mortem examination, laboratory investigations of reactor and dangerous contact animals, herd check testing and re-testing, the administration in tracing cattle movements, imposing restrictions, etc. Taking all these additions and adjustments into account, the cost to the economy at 1983/84 prices of a herd breakdown was estimated at some £5,700 for a confirmed incident and £1,500 for an unconfirmed one. During the period 1976-1985 about one half of all breakdowns were confirmed. On this basis the benefit gained by preventing a "typical" herd breakdown might be taken as the simple average of the two figures, or £3,600.

Economic costs: The measurable costs of badger control consist of the public expenditures on the resources used in the operation. These fall into two classes - direct costs of removal operations in the field, and indirect costs of central administration, data collection, veterinary investigation and laboratory examination of badger carcases etc. They can be estimated only as an aggregate over a period for which the policy was in force, not on an annual basis or attributable to individual breakdowns. Even then, it requires a major exercise of accounting to identify and allocate the relevant costs, for many are incurred jointly with other activities. For example, the specific proportion of the total running costs of Veterinary Investigation Centres in the South West region attributable to the badger operations is not easily discerned, nor is the relevant share of central MAFF administrative costs. Such calculations are an everyday issue for accountants, who have devised rules and procedures to avoid having to think about what the resulting numbers actually mean. The economic analysis has to start, however, from the presumption that a distinct set of additional costs have been incurred within the system, and that those costs would be avoidable if badger operations ceased. But since no attribution of costs to the programme can be definitive, the figures can only be estimated reasonably within a range of values.

Taking all these considerations into account the accumulated costs of badger control, from the financial year 1975/76 when it commenced up until 1983/84, were estimated at some £11.3 million (lying within a range of £10.3 - £11.8 million). This figure includes also the resources used in veterinary, ecological and other research programmes directed towards the study of bovine tuberculosis and badgers, estimated at £3.6 million over the period. Although undertaken as part of the attempts to deal with the "badger problem", this research may still have gone ahead even had there been no badger removal. Consequently it is held aside for present purposes and not treated as an integral part of control costs. This reduces the central estimate of directly attributable policy costs to some £7.7 million at 1983/84 prices.

WAS IT WORTH IT?

We now confront the statistical analysis presented earlier. How many breakdowns, each of which would have caused a measurable loss to the economy of some £3,600, have been prevented by this public expenditure?*

Hypothesis B, which identifies a progressive decline in tuberculosis incidence after badger removal commenced, allows one estimate to be made. A projection of the pre-1975 regression line estimates the "without policy" incidence of breakdowns; calculating the post-1975 regression line estimates the "with policy" incidence. Applying these levels to the number of cattle herds at risk in each of the years 1975-1984 yields predictions in terms of estimated numbers of breakdowns. By assumption, the difference between the two sets of predicted values measures the breakdowns prevented. These

*The following cost and benefit computations involve comparing just the totals of the estimated annual benefits and costs at 1983/84 prices, regardless of the year in which they arose. The correct procedure would recognise that costs and benefits were incurred at different times over the 8-year period, so each annual amount should be brought to a common base by compounding at an appropriate rate of interest (the Treasury "test" discount rate for this purpose is 5 per cent) to yield totals with a present value as at 1983/84. It would be crucial to make this adjustment if the balance between costs and benefits were narrower than is the case here, or otherwise the wrong judgement could be made.

results are shown in Table 2.* An estimated 310 breakdowns were saved over the period, representing measured benefits amounting to £1,116,000. This implies a benefit/cost ratio of 0.145 for the whole £7.7 million expenditure programme (i.e. £14.50 benefit for every £100 expended), or an excess of measurable costs over measurable benefits of £6.584 million.

Table 2. Predicted incidence of herd breakdowns in the South West, Model B

Year	Actual number of reactor herds (confirmed & unconfirmed)	Numbers of reactor herds predicted from Model		
		Trend after badger control (a)	Continuation of pre-1975 trend (b)	Difference following badger control (b) - (a)
1975	507	452	452	0
1976	385	430	439	9
1977	246	411	428	17
1978	201	399	425	26
1979	166	371	404	33
1980	297	354	395	41
1981	214	340	388	48
1982	213	327	383	56
1983	228	311	374	63
1984 (part)	49	74	91	17
Totals	2783	3469	3779	310

As the statistically "best" model, Hypothesis C should perhaps be the basis for the benefit calculations. An extreme interpretation of this hypothesis attributes a generally lower but constant level of breakdowns post-1975 entirely to factors other than badger control. As discussed earlier, it is hard to believe that removing infection from the badger population has had no affect on the occurrence of the disease in cattle herds. For analytical purposes, then, let us take the other extreme and assume that the apparent steep drop in incidence in the mid-1970's **was** due to badger removal, and use the regression model to compute the estimated number of breakdowns thereby prevented. This procedure is analogous to simply comparing the mean annual levels of incidence before and after the introduction of gassing, and may serve as a proxy for the hypothesis that badger removal has prevented the rise in breakdowns that would otherwise have taken place. The results of these assumptions are given in Table 3. The difference between the two projected time paths after 1975 gives a total of 1,332 breakdowns that were prevented up until March 1984, representing a measured benefit of £4,795,200. This is probably the closest one can get to an upper estimate of the benefit-cost ratio for the policy. It is still no more than 0.623 and implies that, even under these generous assumptions, measured costs exceeded benefits by some £2.9 million.

*The last financial year in the cost evaluation ended in March 1984, so the relevant numbers included for that year were taken simply as one quarter of the annual figure.

Table 3. Predicted incidence of herd breakdowns in the South West, Model C

Year	Actual number of reactor herds (confirmed & unconfirmed)	Numbers of reactor herds predicted from Model: Trend after badger control (a)	Continuation of pre-1975 trend (b)	Difference following badger control (b) - (a)
1975	507	458	458	0
1976	385	355	445	90
1977	246	256	435	179
1978	201	253	432	179
1979	166	240	412	172
1980	297	234	404	170
1981	214	229	397	168
1982	213	225	392	167
1983	228	219	385	166
1984 (part)	49	53	94	41
Totals	2783	2522	3854	1332

Hypothesis C proved better than Hypothesis B on the conventional statistical tests, and its predicted time path of breakdowns is closer to the numbers which actually occurred. (It predicts some 9 per cent fewer than were observed between 1975 and 1984, while Model B's predictions are 25 per cent over the observed total.) If we accept Model C on purely empirical grounds as the best explanation, it would be helpful if a convincing technical explanation for the observed structure of breakdowns could be advanced to go with it. Without that, we have no way of partitioning the observed decline in incidence between the various postulated causal factors - and hence no firm basis upon which to assess the benefits that can be attributed with some confidence to the removal policy.

Even so, even under the best assumptions the economic evaluation lends no direct support to the view that badger removal was worth undertaking. Two major caveats should be noted at this point. First, there is a range of uncertainty surrounding the assessed levels of cost and benefit. The total costs may be overestimated insofar as much of the central MAFF expenditure might be the same even if there were no badger policy, or if it was conducted at a different level. The benefits may be underestimated because, since badger removals lower the risk of both current and future breakdowns, further benefits to the recorded expenditures should accrue after 1983/84.* Second, it must be clear that the costs and benefits considered are only those that could be identified and assigned a monetary value. There are in addition a number of real but unquantifiable economic costs and benefits that lie quite

*Though using even the lowest estimate of the measured net costs of the policy (£2.9 million) over 800 further breakdowns need to be averted solely as a result of expenditures up to 1983/84 before the breakeven point is approached - that is, about 60 per cent more than attributed to the programme already.

outside any formal analysis. Many of these are identifiable in principle but not readily measured - the benefits of reduced damage by badgers to hedgebanks and grassland, the costs incurred by animal rights activists in trying to disrupt badger killing, etc. Others are even more elusive. One cannot reasonably value the benefit to society of someone not contracting tuberculosis; badgers have no market price, so no particular cost can be attached to a reduction in their numbers, or to the genuine welfare loss felt by the large number of people who are troubled by the whole idea of killing badgers. These are real elements of economic cost and benefit, but they fall outside the everyday framework of market valuations and so no data is ever generated to reflect them.

However, it is never the claim of economic analysis to reduce everything to monetary terms. Rather, the aim is to subject to formal assessment and comparison those elements that **can** reasonably be quantified and valued. By doing this, those that can only be handled by judgement rather than calculus are made clear. Attention is then focussed on judging the balance of these residual costs and benefits, set against the net monetary sum which summarises the balance of the measurable components. In the present context the relevant question becomes: "Is it likely that the unmeasured benefits to society of badger control sufficiently exceeded the unmeasured costs to have made it worth spending £2.9 million in gaining them?" The answer to that question can only be a subjective judgement - but it should force the proponents of the policy to identify clearly their case. One can only say it seems unlikely.

DID WE WANT TO DO IT?

The final major question in this judgemental arena is really a political one, and brings us full circle back to the first question posed at the outset. Does our society want to continue bovine tuberculosis eradication towards the technically achievable minimum level? "Society" in this sense is a collection of many interest groups, each with a valid view on the issue. While requiring information and skills offered by different disciplines, the answer involves much more. The decision is strictly a value judgement, a statement of group preference, and so the question cannot properly be handled in the "rational" manner that our science or professional allegiance leads us to presume.

The particular evidence presented here points towards a decision to cease badger control. But a consideration of the parties to any final assessment suggests ultimate conflict more than obvious compromise. The farmer will be indifferent as long as his livelihood is protected or any income losses are compensated. The veterinary surgeon will prefer to remove infection sources in badgers and any other wildlife as a threat to improved (domestic) animal health. The public sector accountant will wish to ensure the budgetary costs of control operations remain at an acceptable level. The economist will advocate only that level of resource commitment where the benefits gained can be justified relative to the value of the resources in other uses. The conservationist will be concerned that the wildlife population is being unnecessarily, and perhaps unacceptably, interfered with. The epidemiologist will sensibly reserve judgement on the programme until much more information is available to discern the interactions of the disease within and between the two populations. The animal rights activist will object on principle to the killing of badgers in pursuit of marginally cheaper agricultural products. The policy administrator will want a programme and procedures that are manageable and defensible. And the large bulk of the population will individually have little information and probably no considered view on the issue, but nevertheless in aggregate may hold an attitude that is not entirely indifferent.

In the end, assessing the policy of badger control and its effects on the incidence of bovine tuberculosis is a political task.

Acknowledgements

John Wilesmith and Aidan Power kindly provided the primary data upon which most of this paper is constructed, and many ideas arose out of discussions with them. The author wishes to express his sincere thanks, and to affirm that any errors and omissions are there despite, rather than because of, their efforts. Steve McCorriston gave valuable assistance in computing the statistical models.

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EPIDEMIOLOGICAL WORKSHOP

A CASE STUDY OF BOVINE VIRUS DIARRHOEA

DISCUSSION

ACKNOWLEDGEMENT

The recording of this discussion was transcribed by Mrs Christine Brown, Rona Hunter and Margaret Nicol.

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Davies (Chairman): This discussion is about probably the most important current disease of cattle in the U.K. - a disease about which a lot of information has been gathered over the last 5 years. Four areas were covered by the speakers in the BVD session. First, Jim Harkness presented technical aspects of the disease and outlined three strategies that might be considered in relation to BVD:

1) inactivity;
2) testing and culling;
3) vaccination.

Secondly, Mike Richards described methods of calculating incidence of infection. Thirdly, Richard Bennett discussed decision analysis as a tool for the veterinary advisor who is faced with BVD on the farm. Finally, Keith Howe considered the effects of the disease on output and the way that they might be considered nationally, including possible strategies for control.

Hugh-Jones (to Richards): We frequently make a mistake when working with age-related seroprevalence. Your approach works very well for cattle that do not die or that have persistent titres. However, you need to consider the animals as a cohort. Thus, if the disease does not have an effect on mortality, there is no difficulty. However, if animals die (or are culled) then you are really looking at just the survivors, especially in a dairy population. I think you have underestimated the true incidence by not taking into account mortality and/or preferential culling when lesions appear.

Richards: I do not think that there is a problem with the survivor curve* and the so-called 'catalytic model' applied to it in my paper. We are not losing animals as a result of BVD virus infection because acute infection with BVD virus is not a substantial cause of death or culling among adult cows.

Hugh-Jones (to Richards): Why does the curve flatten-out?

Richards: It flattens out because an animal cannot be infected again, and it reaches a plateau at around 70% because approximately 30% of herds do not have BVD virus infection at any one time. However, this is an underestimate because there are more cows of the lower than the higher ages. Therefore, one should correct the estimate for populations of different ages. I think this is a small factor. The biggest problem is the actual time of infection relative to the stage of pregnancy. There is still a feeling at the back of one's mind that the most likely time of infection is probably in late pregnancy or just after calving, because this is the time when newly calved heifers are introduced into the adult herd. If this has a substantial effect then it would cause the catalytic model's estimate to be a considerable overestimate of the number of persistently infected foetuses.

Hugh-Jones (to Howe): One has to remember sociological components, too. If farmers are going to make the same amount of money with less animals, following control, do they maintain the same numbers of animals and put their profits into other enterprises, or do they reduce their numbers and increase leisure time - go fishing, perhaps? Are they truly only profit orientated - or do they go fishing?

Howe: My answer is bound to be a simplification of a complicated situation, and may appear contradictory. Of course, if some farmers already consider themselves sufficiently well-off, then the potential for making even more

* The curve is constructed using the data in Table 1, p.9.

economically-efficient use of their farm resources may well be unrealised; they may increase their leisure time. However, let me go back a stage to remind you of the way in which prices of products would be expected to change following productivity increases in any particular sector; the cattle sector, of course, is the one with which we are concerned. In some respects, the effect is analagous to what happens in agriculture if, as has happened in European Community milk production, an output constraint frees resources previously devoted to one line of production for use in other farm enterprises. The aggregate response from the decisions of the many individual farmers affected is observed. This is what everybody fears because if might simply mean the build-up of surplus problems in other commodities with consequent downward pressure on their prices. In the circumstance of animal disease control, resource reallocation may well take place but the difference is that increased production of the relevant livestock products will be the result anyway, because disease control represents a direct productivity improvement. Other things being equal, prices for livestock products will move downwards to an extent dependent on the presence or otherwise of any market intervention.

Most important, however, is that there is substantial evidence to suggest that farmers have been forced into the position of being profit maximisers, irrespective of their own wishes. This is because of the way in which agricultural policy has worked. Farm prices have been administered at higher levels than would otherwise exist in a free market. Price supports are 'capitalised' into fixed asset values - particularly land. In other words, land prices have risen very substantially in the past twenty years or so, largely as a consequence of agricultural policy. Also, there is evidence that product prices for farmers have fallen in real terms for some time - certainly in this country. It is true that input costs have fallen, too, but by not as much. Therefore, farmers have found themselves in the position of facing a price/costs squeeze. If you are in that situation all that you can do is to try to maintain profit by increasing productivity. That, more than anything else, is the cause of European Community agricultural surpluses. In this context, I would expect that the opportunity to increase productivity by virtue of a disease control programme is likely to be attractive to farmers.

Rowlands (to Richards): I support Martin Hugh-Jones' comments about the seroprevalence curve because there may be other reasons associated with BVD infection for the culling of a cow, such as loss of milk production. Is a study needed to investigate this model further, and what study might be proposed?

Richards: The study should be of cost elements relating to the individual animal. One of the most difficult costs is that of an episode of acute infection. The two areas in which there are likely to be associated costs is in milking cows, where there could well be a fall in milk yield, and in calf rearing. There can be a substantial outbreak of acute BVD in a group of calves which can predispose to an epidemic of respiratory and other problems. I would support any work to estimate a fall in milk yield associated with acute outbreaks.

Done (to Richards): Given the complication of milk loss, all the other interacting factors, and the difficulty of conducting a study, how serious would it be if such a study were not done in the near future? We could, instead, use the 'cockshy' figures to run the model for several years. What I am really asking is: how sensitive are the milk loss and mortality components within the syndrome?

Richards: I think it is unlikely that milk loss is a substantial cause of culling of an infected cow.

Harkness: We have encountered outbreaks of acute BVD in adult cattle in which there have been deaths. This is also recorded in the literature. However, one recent such outbreak was not an uncomplicated infection. It occurred on a farm on which there was not only active BVD but also active Q fever and leptospirosis. It is very difficult to know in these circumstances just how much of the mortality was attributable to BVD and how much to the other pathogens that were present. This clearly is an area worthy of investigation but I do not know exactly how one would design a suitable study.

Howe (to Done): The starting point is clearly to take the data that you have and use them as input for the current models. Then you can examine the sensitivity of your predictions to variations which you impose on parameter values. This is the appropriate approach, given the uncertainty about some of the estimates with regard to the effects of BVD.

Giles (to Harkness): What are your views on the current alternatives to vaccination, considering that there are no licensed vaccines, and what are your comments on the likely cost of infection in milking cows? The effect on reproductive status can be much more costly than a drop in milk yield. We looked at one herd recently where sero-conversion occurred over one year. Of the cows that sero-converted, two aborted, one was barren and one produced a persistently infected calf. There were approximately 2.3 services per conception. This was a fairly heavy loss without any obvious disease in the cows. Would you recommend taking serum and instilling it into the nose of calves and, if so, at what age?

Harkness: If virus is to be transferred deliberately within herds then it ought to be undertaken only after careful consideration because of the risks of transferring other agents, such as enzootic bovine leucosis, in the course of the action. Obviously, enzootic bovine leucosis is not a very common problem, but this is the sort of risk which would have to be taken into account. The persistence in calves of colostral antibody to BVD virus is probably about 6 months. That is about the upper limit. Thus, if calves are to be exposed, they ought to be slightly older than 6 months before this action is undertaken.

Giles (to Harkness): What is the progress with vaccine development?

Harkness: There are several groups interested in producing a vaccine for licensing in this country, but I am not in a position to tell you what stage they have reached and whether or not they have applied for a product licence. I should guess that a suitable product will be available within the next two years.

Alenius: I have been working with BVD for over four years now. We have an inactivated vaccine which is quite effective when tested in sheep. However, I still think that the control policy in the future should be to test and eliminate, or to just test to establish how many farms are free of BVD, and then protect animals on these farms. This will be the most economic way of preventing losses from BVD.

Harkness: I am very glad to hear that you are more optimistic than I about the way in which a test and cull strategy can be applied. I do not know how your cattle industry operates in Sweden, but it may be more difficult for farmers to operate this strategy in the UK. It is very difficult in practice to apply the strategy in rearing units where farmers are buying-in calves.

Alenius (to Harkness): What is the number of BVD-free herds in the UK as a proportion of the population?

Harkness: The only data we have are from about 1978. At that stage, 92% of herds had antibody, and almost 70% of adult cattle had antibody. Thus, only 8% of the herds seemed to be free of evidence of recent infection with BVD.

Sharp (to Harkness): I should like to comment on the rate of transmission. The field experience of some of us has suggested that in a susceptible herd of pregnant dairy cows the dissemination of infection would appear to be fairly rapid following initial introduction of the virus. This can be gauged by the subsequent effect on the herd in terms of the pre-natal infection that is reflected in the high numbers of persistently infected animals that are born, as well as the other more interesting pathological phenomena that arise post-natally. This often is a reflection of the management, particularly the calving pattern. Thus, in some of these herds, there are certain months that are more hazardous than others with respect to introducing persistently infected animals. In contrast, there are reports, (e.g. Barber et al., 1985*) indicating that introduction of the virus appears to be followed by very slow dissemination through the herd. This is very difficult to understand, but could occur because there is partial immunity in the herd; antigenic variants may be important, too, in this context. Finally, a comment on the traditional British practice of testing and culling: I have grave doubts about this approach to BVD control. Although there are some instances when the onset of a problem can be associated with the purchase of a persistently infected animal, there are several other instances in which there is no evidence of cattle being brought onto a farm. We should be very cautious about advocating any particular policy until we can safely exclude the possibility of sheep and deer as potential reservoirs of infection. Therefore, vaccination still appears to be the most attractive approach currently. Do you think that viral variation is important; and is the test strain of virus we have been using, NADL, suitable diagnostically?

Harkness: There is a great deal of antigenic variation among BVD field strains circulating in this country. Its effect on foetal immunity and cross-protection is not very clear. Experiments in calves indicate that quite dissimilar variants of the virus will cross-protect against post-natal infection, but whether this extends to protection of the foetus is another matter because just a transient viraemia will expose the foetus. The strain of virus that we have used for some years, type NADL, is not in our opinion particularly typical of circulating field strains today. This strain was isolated in America 30 years ago. Therefore, it is not too surprising that the strain is rather different from the ones we are currently seeing in Europe. Our diagnostic laboratory intends in the future to use a different strain for diagnostic tests which is rather like the Oregon C24V variant virus. We have just completed a small study which shows the extent of the missed diagnoses if type NADL is used.

Done (to Harkness): Richard Bennett and I have considered the efficacy of vaccination. Generally if a vaccine is safe enough and cheap enough then it need not be perfect. What would you postulate as the requirement for a BVD vaccine in general, and is there a case for a new one, as distinct from using vaccines currently available from other countries? Is there any useful distinction to be made between a vaccine used prophylactically to prevent a problem occurring on a significant scale, and one used metaphylactically, as in vaccinating out of trouble? In other words, if we have got a cheap, safe vaccine that protects 50% of foetuses from transplacental infection, how much money should we be prepared to spend on improving the product?

* Veterinary Record 117, 459-464.

Harkness: The primary requirement for a vaccine is that it should be capable of protecting a large proportion of the foetuses because most of the economic losses accrue from the results of foetal infection. The problem about importing vaccines from other countries is that some of them are unsafe, having serious adverse reactions, although they provide adequate levels of protection. These vaccines are foetopathic when used during pregnancy. They also appear to cause immunosuppression in vaccinated cattle, which can precipitate or potentiate intercurrent disease. In addition, they are capable of precipitating mucosal disease in a proportion of persistently infected animals which are vaccinated. Information on the efficacy of foetal protection is unavailable for most vaccines because most manufacturers have not been asked to show that their vaccine is efficacious in protecting the foetus.

Done: In relation to safety, might we be prepared to accept an inactivated vaccine?

Harkness: The remarks I made about vaccines were mainly concerned with the live variant vaccines and not with the inactivated vaccines that are now appearing on the market in different parts of the world.

Done: Differentiation needs to be made between risk at national level and risk to the individual animal. Clearly, risk at national level is something that a government might not be willing to tolerate, but risk at the individual animal level could well be acceptable as long as the risk is quantifiable. I suggest it is for the individual farmer to decide on that risk. Future studies should be of risk and efficacy factors, bearing in mind that the ability to protect a foetus from transplacental infection is one of the most important requisites of a BVD vaccine. Do we need to know any more pertinent facts and, if so, how are we going to get them; or can we use the crude data that we are putting into our models?

Bennett: One of the uses of this type of model is to run sensitivity analyses. One can then identify those factors that particularly affect the costings that are produced. Our model is particularly sensitive to the assumed risk of exposure to the virus. We used a probability of exposure of 0.01 (1%). If the probability were just beyond 0.02 (2%), then the strategies change. In our example, the best strategy would be to test all replacement stock. This illustrates that the model can indicate areas where further information is needed, and where more precise estimates of model parameters are required because the parameters have marked affects on the results.

McInerney (to Bennett): Is your model for real decision making on the farm - is it an advisory model? In other words, if you were an adviser with data, would you feel confident in using this kind of analytical approach to persuade a farmer to put his money down 'on one side of the line or the other'?

Bennett: Our model could be a useful, practical tool. It is on a computer spread sheet. Therefore, it is easy to 'play the figures' to see what results are generated. The problem, of course, relates to the sort and reliability of information that is available on epidemiological characteristics and incidence of disease, which, in turn, is associated with the model's sensitivity to these variables. If estimates of a parameter are only slightly wrong, the model is tested by changing the parameter by a very small amount. It affects the outcome drastically, then one is going to be a lot less confident in trying to use the model to advise farmers on what they should do.

McInerney (to Bennett): The decision tree approach is very good because it is systematic. It is very open: it sets out quite clearly what the choices are, and therefore it is very informative. However, I am a little concerned that your model is rather too simple in capturing the decision-making approach of farmers for whom the riskiness of outcomes, as well as the level of monetary gain, are important. The maximum EMV is the 'best' strategy only for those farmers who are 'risk-neutral'. The majority of us are 'risk-averse' to a greater or lesser extent, and for large numbers of farmers it is the possibility of a major loss, and the consequences if it occurred - even though the probability may be very low - that is most disturbing. In other words, it is not maximising in the long run but surviving into the long run that matters, so that those long run values can manifest themselves. How would you handle the strictly 'risk-averse' situation, in which it is worthwhile paying money of some sort, on an annual basis, to avoid a large loss which may have a low probability of occurring, but is very serious when it does occur?

Bennett: I take your point entirely. The EMV does not automatically choose what strategy one selects. One can run the model accordingly. For instance, instead of assuming that the probability of a herd being exposed to virus by buying-in an animal from the market is 0.01 (1%), one can change this probability to 1 (100%) which is what will happen if a persistently infected animal is definitely bought from the market. The outcome is then costed, and one can decide whether or not one can afford to take that risk. We have started to adopt this approach with our model. However, it seems to be particularly complex in relation to BVD, which has been particularly difficult to model. Therefore, unless our model is further refined and tested, I certainly would not use it to advise farmers on what they should do. Nevertheless, in a few circumstances, it is starting to indicate clear strategy choices. For example, if a farmer bought-in a persistently infected animal and could afford the short run loss then, in our example, he would actually be better off in the long run doing nothing. As an improvement, he could pay an insurance company £30 a year, if the company were willing to insure against the possible losses.

Done: Richard Bennett and I do not see the model simply as something which is going to give you the answer. It produces an hypothesis which you then have to consider seriously. As a 'dyed-in-the-wool abdominal-judgment' type of veterinarian, I feel that this sort of thinking is particularly valuable because it tends to move the centre of decision 'from the abdomen towards the head', and tends to substitute analysis and decision for opinion. Often, we have a feeling, we give an opinion, and we make up our mind. The opinion then has to be put down or vindicated by an adversarial process which only considers one alternative at a time. The beauty of this modelling system is that you can have everything 'from the sublime to the ridiculous'. For example, insurance is one of the options that is not normally considered. The National Farmers' Union might be better producing livestock insurance schemes for some diseases, with limited availability, rather than stimulating open-ended research with no objectives.

Bennett: The idea of this sort of model is to provide a farmer with more, and hopefully better, information on which he can make a decision. He is the person that has to suffer the consequences of any decision. Therefore he should be the decision maker. He makes the decision; an advisory veterinarian produces information for him on which to base such a decision. One of the best uses of this sort of model is as a research tool: to run it and investigate various avenues, various strategies, and so on, rather than to think that it gives perfect answers.

Booth: What Jack Done said is obviously directed slightly at the Milk Marketing Board as well as the National Farmers' Union. It is perfectly true that both organisations, and many others, have been asked to put their hands into their pockets to finance research. However, if 92% of herds have some evidence of infection, BVD is a classic example of a disease that would not be suited to an insurance policy. A herd also has been described that was infected not only with BVD virus but also Q fever and Leptospira spp. It would be very difficult indeed to decide how to pay out in such circumstances. Colleagues in the profession who are working in research would not wish to see us going down this avenue with this particular disease, although there may be other suitable diseases for insurance compensation.

Richards: To return to the model: we call it a decision model but really it is a financial model, that is, an accountancy type of model. When we were discussing this some months ago, we had difficulty putting the epidemiology clearly into a decision tree framework. This is a problem with the decision tree approach. You cannot get a very good description of the epidemiology in a decision tree. Alternatively, if you write an epidemiological model which has all the ongoing structure of the herd and its transmission of disease, then it is difficult to put the herd into a decision tree framework. A difficulty with a decision tree is that you have to look very hard at the epidemiological assumptions that are inside it.

Barros (to Richards): The decision tree is strange because you may be interested in what happens when you do not have an event. You might consider probability of exposure, in which circumstance there are susceptible animals, but there may be no infection; the tree then dies. Similarly, if an animal is not susceptible the tree dies. Thus, you are only really interested in the product of the positive outcome. Therefore it is not really a decision tree. You could construct a base case of positive probabilities - probability of exposure etc. Then, when applying the strategies, there is a way of changing the probabilities. For example, you vaccinate, then you change the probability of infection and you buy disease-free stock, then you change the probability of exposure. However, this is not really a decision tree.

Bennett: I accept that this is not a standard decision tree. However, if one were to adopt your approach, all the probabilities are distributions as well, and we are taking average cases; it is very 'black and white'. Actually, there is a range of outcomes, which is what normally occurs in a decision tree with a range of probabilities. If we were to consider such probabilities, the model would get very complicated indeed. I am not absolutely convinced that it would be necessary anyway. Instead, you could use distributions in place of the single probabilities. Changing the probabilities according to strategy is what we have done in that we have altered the probability of virus exposure according to an assumed efficacy of the vaccine.

Chamberlain: You have a model containing several guessed probabilities, and you admit you have made a lot of assumptions in it. One of the functions of a model produced at this stage in a piece of research is to enable sensitivity analysis to be undertaken on all of the various probabilities. You then have a pecking order that will say: 'this factor is important, go and find a better answer; that factor does not matter, do not spend any money on that'. Do you have such a list for us?

Bennett: You are absolutely right. Sensitivity analysis is very important but we have not reached that stage yet.

Richards: If you do sensitivity analyses on the model for an outbreak in a single herd, or the risk to a single herd, that tells you the sensitivity in the circumstances of that herd. If you want to find out what is important over the country as a whole, you need to determine the circumstances of the average herd.

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