Netherlands Journal of Agricultural Science 44 (1996) 89-102

Outline for an integrated modelling approach concerning risks and economic consequences of contagious animal diseases

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Received 9 February 1996; accepted 24 May 1996

Abstract

Outbreaks of contagious animal diseases pose a major threat to livestock production. Especially outbreaks of diseases that are on list A of the OIE are feared because these outbreaks will often result in serious economic losses, especially for major exporting countries such as The Netherlands. Management decisions in this area may have a large impact, but are usually based on scarce and unreliable information. Extensive research has been done on contagious animal diseases but an integrated model which combines the various aspects of outbreaks and risks with economic consequences is still missing. A flexible model with the possibility of evaluating the consequences of various strategies can be an important tool to aid in policy and decision making. In this paper a modelling approach is proposed which should lead to such an integrated model. In the paper the approach (a general framework) is outlined and several techniques to be applied are discussed. Subjective mathematical probability seems to be an appropriate technique as a basis for the model. In developing the model, special emphasis should be given to gathering the input data, which could include the use of expert panels. Promising techniques to deal with expert panels mainly originate from the area of marketing and consumer science and include conjoint analysis and the elicitation of subjective probability distributions.

Keywords: contagious animal diseases, uncertain knowledge, modelling uncertainty, virus introduction

Introduction

In 1994, Belgium and Germany were badly hit by outbreaks of Classical Swine Fever (CSF). More than 7.4 million pigs were killed and destroyed, the total costs of this operation estimated at almost 75 million ECU (Vanthemsche, 1995). However, these are only the direct costs (operational costs, market support, sanitary actions). Indirect costs, resulting from market disruption due to export restrictions, are often much higher and account for the major part of the total economic losses due to outbreaks of CSF and other list A diseases (Berentsen *et al.*, 1992; Dijkhuizen, 1988).

List A diseases are defined by the FAO/OIE/WHO Animal Health Yearbook (Anonymous, 1992) as 'communicable diseases which have the potential for very serious and rapid spread, irrespective of national borders, which are of serious socio-economic or public health consequences and which are of major importance in the international trade in livestock and livestock products'. Besides CSF, some other well-feared (because of their economic impact) viral diseases on this list are: African Swine Fever (ASF), Foot-and-Mouth Disease (FMD), Swine Vesicular Disease (SVD), Newcastle Disease (ND) and Avian Influenza (AI). Outbreaks have to be reported to the OIE (Office International des Epizooties) and eradication has to take place according to EC regulations, laid down in so-called 'Council Directives'. For instance, with respect to CSF, the following measures are required (CEC, 1980): rapid detection, confirmation and subsequent stamping-out of infected herds, tracing of risky herds (i.e. possibly infected herds), establishment of protection (3 km) and surveillance (10 km) zones around infected herds with complete movement standstill of all animals, and a continuous epidemiological surveillance within these zones.

Because of the great economic impact of outbreaks, adequate disease prevention and eradication is of major importance. Improvements may be made in various areas, for example the tracing of contact herds (by improvement of I&R systems, Saatkamp, 1996) or the operational management of outbreaks (by using programs such as EpiMAN, Sanson, 1993). A simulation model which is flexible enough to analyse the effects of different strategies (such as the two described above) could be a useful tool to support policy makers in this area. Therefore this paper proposes a modelling approach which (1) integrates the risk and economic consequences of outbreaks, (2) starts after an outbreak occurs in a 'foreign' country that could lead to the introduction of the disease into one's 'home' country, and (3) follows the disease/infection through all the various levels of the production-marketing chain. The structure of the paper is as follows: Firstly a brief overview of related research is presented (with no intention to be complete, only to present the reader with some background information). Then a basic idea of the system is introduced, followed by a discussion concerning the various phases of introduction of virus into one's 'home' country. Next, the general outline of an integrated model is discussed, with emphasis on modelling uncertainty and gathering input information. The paper concludes with further discussion of the issues and concluding remarks.

Background

Extensive research has been done on contagious animal diseases, roughly to be divided into the following areas of interest: (1) the agent that causes the disease, (2) the mechanism of disease transmission, (3) economic consequences of outbreaks, and (4) prevention and eradication programs. Several studies focus on only one of these areas. Studies on vaccines (Terpstra & Wensvoort, 1988) belong to area 1, while studies by, for example, De Jong (1994) primarily focus on the second area:

the transmission of the disease. Sanson *et al.* (1994) used stochastic simulation to model the transmission of FMD virus. The resulting spatial simulation model, called InterSpread, was included in a decision support system, called EpiMAN, developed for use in FMD control in New Zealand (Sanson, 1993).

There is a large number of studies that show overlap in certain areas. Especially studies from a veterinary point of view often combine areas 1 and 2. Examples are laboratory studies to gain insight into the influence of vaccination regime on immune response (Corthier, 1978), or studies in which the influence of various levels of virulence on symptoms and detection of infected animals is evaluated (Wensvoort & Terpstra, 1985). Although areas 1 and 2 are still important, the existence of dense populations of livestock in certain countries (within the European Union (EU) e.g. The Netherlands, Belgium, Germany and Italy), the increasing importance of international trade of livestock and livestock products, and the fact that countries are allowed to implement trade bans by only the slightest suspect of outbreaks (to protect their own animal health status, or as some might say, protect their national livestock production), induced the interest in economic consequences in combination with prevention and eradication programs (areas 3 and 4). Studies in these areas include, among others, Berentsen *et al.* (1992), Caporale *et al.* (1981), and Davies (1993). Berentsen *et al.* (1992) used a simulation approach to determine the economic consequences of alternative strategies to prevent and control FMD in The Netherlands. In this study, also the influence of outbreaks on the export was taken into account. This aspect becomes increasingly important, especially for countries that suffer from outbreaks on a more or less regular basis and for countries that are historically free of certain diseases and wish to maintain that status. The latter concerns for example countries blessed with physical isolation, such as Australia and New Zealand. Risk assessment studies, concerning import of livestock products, are becoming of major importance. General outlines for developing a quantitative risk assessment study when international trade is involved are given by Miller *et al.* (1993) and MacDiarmid (1993). Other studies in this area include Heng & Wilson (1993) and Wilson & Banks (1993).

It can be concluded that many researchers have explored the area of contagious animal diseases and their control. Many attempts have been made to construct models which could support decision makers in a useful way (among others Berentsen *et al.* (1992); Sanson (1993)). Although these attempts have led to a number of useful models, an integrated model which includes the various aspects of outbreaks of contagious diseases and which combines risks with economic consequences is still not available. In the remaining part of this paper, an attempt will be made to describe a modelling approach which does integrate these aspects.

Scope and definitions

To structure the ideas on modelling risk and economic consequences of contagious diseases, a system, a world, is assumed which contains small units (the small blocks), surrounded by a 'border' (Figure 1). The part enclosed by the border might be seen as a population. The border divides the world into an endogenous part (the population) and an exogenous part. The exogenous world is regarded as being uncontrollable and unpredictable. There are all kinds of contacts possible between the endogenous and the exogenous world; animals, human beings and commodities, all pass the border on a frequent base. Also between the small units within the borders all kinds of connections are possible. Some connections (but not all) are presented in the diagram by arrows. If somewhere in the exogenous world an outbreak of a contagious animal disease occurs, there is a probability that the pathogen will spread into the endogenous world (the population) and cause outbreaks in the small units.

To cause such an outbreak, susceptible animals should be available and the pathogen has to be transported in one way or another. Risk factors are factors which can be responsible for this transport. The definition of risk factors as used in this paper is rather broad and includes all factors that can be responsible for the pathogen transport. Using this definition, also vectors (defined by Ahl *et al.* (1993) as 'organisms which can carry and transmit disease') and commodity factors (defined by the same authors as 'parameters specific to an animal or animal product which affect the likelihood that the unit, if contaminated, will carry, maintain and transmit an agent after arrival in the country of destination') can be seen as risk factors. From the literature it becomes clear that most diseases of list A of the OIE have many risk factors in common. Risk factors can be roughly divided into four groups: livestock (including livestock products), human beings, materials and air. The relative importance of these groups differ per disease, e.g. 'air' is an important factor for FMD (Mann and Sellers, 1989), while feeding of swill (organic waste, belonging to the group 'livestock products') is said to be the major cause of several outbreaks of ASF (Becker, 1987).

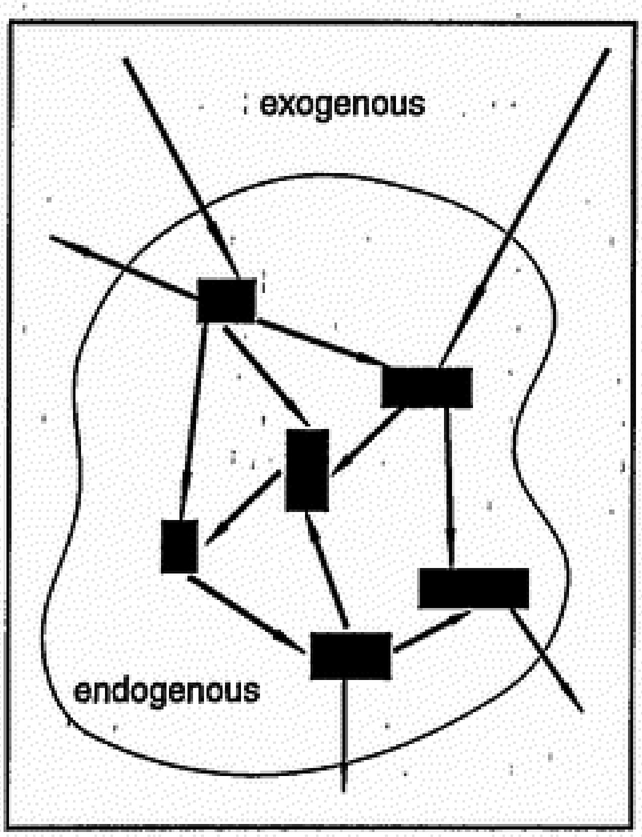

Figure 1. Schematic outline of a system containing an exogenous and an endogenous part.

The first outbreak occurring within the population (the endogenous world) is commonly defined as the primary outbreak. After this outbreak, the pathogen can spread to other units (also endogenous) via the risk factors, and cause secondary outbreaks. As indicated by the arrows in Figure 1, there are contacts between the block units within the endogenous world. That means that the status of one unit may influence the status of a neighbouring one. For example, if the units represent individual farms, a farm with a poor hygienic status and regular import of animals may increase the risk of infection for a neighbouring farm.

Using the diagram in Figure 1, it is possible to modify the scope of the problem under consideration by adjusting the border line (thus adjusting what is considered to be a population). When considering a primary farm, the border will be the fence around the farm and the small block units the different stables. Expanding the scope, the blocks could present farms and the border could be one of a province, or a country. Expanding even further, the population could be the EU, with the member states as small blocks.

Concerning the approach described in this paper, the endogenous area covers not only the 'home' country, but also several other countries, indicated as contact regions. A contact region is defined as a (part of a) country which has a direct or indirect contact with the home country which, when the region suffers from an outbreak, can lead to the introduction of a virus (due to risk factors) into the home country. The problem of how the virus has entered these contact regions and caused an outbreak has not been incorporated because this is part of the exogenous world.

Towards an integrated approach

Most studies concerning risk and economic aspects of contagious animal diseases are meant to be useful in risk management. Risk management has been defined by Ahl *et al.* (1993) as 'the pragmatic decision-making process concerned with regulating risk'. A somewhat similar definition has been given by MacDiarmid (1993). Both definitions regard the process of identifying the sources of risk and assessing the risk as separate activities. However, risk management is based on the results of these activities and cannot be seen separately. Therefore, a good risk management plan includes all these activities and consists of five basic steps:

1) risk identification;
2) risk assessment;
3) assessing risk attitude;
4) developing alternative risk management strategies;
5) analysing and evaluating strategies.

The approach proposed in this paper aims at incorporating these five steps into one generally applicable model. During the developmental phase, steps 1, 2 and 3 will be taken. With the resulting model it should be possible to take steps 4 and 5.

The flowchart in Figure 2 indicates the several phases which are considered in the approach suggested. The model starts with an outbreak in a contact region. Spread of the pathogen followed by an introduction into the home country can cause a primary

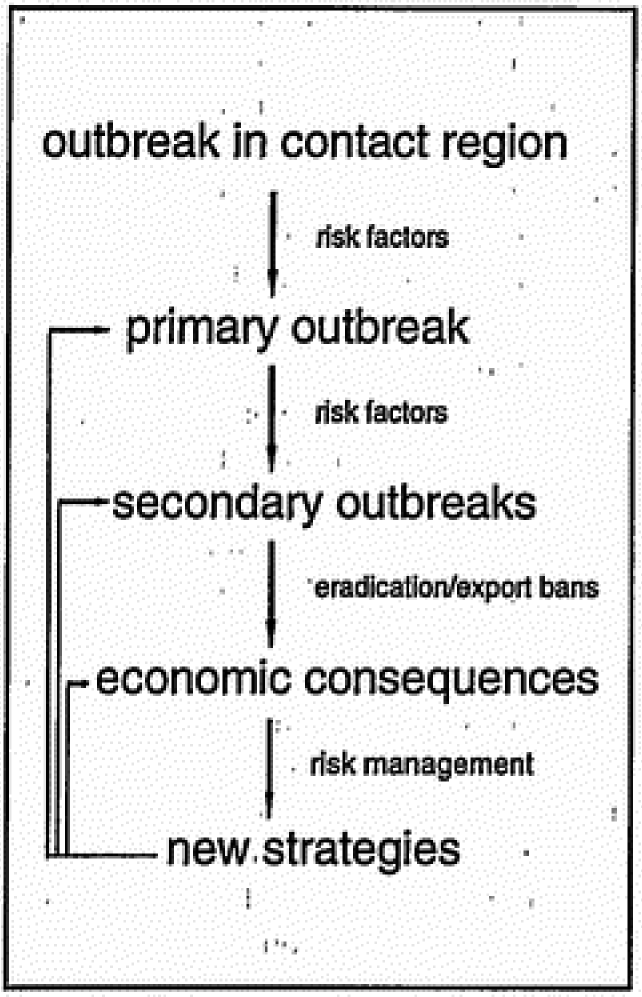

Figure 2. Various steps of the integrated outbreak model.

outbreak. Due to transport of pathogen by risk factors, secondary outbreaks are likely to follow. To model these phases it is necessary to perform steps 1 and 2, i.e. identify the sources of risk (contact regions and risk factors) and assess the risks involved.

Following Figure 2, outbreaks will activate an eradication program containing slaughtering of animals in affected regions, export bans etc. These actions have economic consequences. Evaluation of the consequences can lead to new policies (or strategies), developed by the people responsible for the risk management (step 4: developing alternative risk management strategies). Choosing a new strategy will, however, depend among other things on the evaluation of the expected costs and benefits of this strategy. Costs not only for developing the strategy (e.g. costs for establishing and maintaining prevention measures), but also for bearing the (negative) consequences of the possible risks connected to that policy (e.g. losses due to eradication when an outbreak occurs). Typical for the type of diseases under consideration (viral diseases of list A, as mentioned in the introduction) is that the probability of introduction of a virus in a certain country is low. However, if the virus has been introduced and causes outbreaks, the consequences are generally huge. But while these losses are expected to be large, they might vary to a large extent between outbreaks. Berentsen *et al.* (1992) estimated total losses from FMD at between US$ 45 million and 5 billion, depending on region (animal density) and eradication strategy. Determining the optimal strategy to deal with such uncertain situations requires knowledge of the decision maker's risk attitude. The decision maker has to find the optimal trade-off between expected monetary consequences of strategies and the risks involved (step 3 of the risk management plan). This is important in order to enable decision makers to use the insight gained by model results (number of outbreaks, magnitude of the economic consequences) to develop alternative strategies (step 4) and analyse and evaluate these strategies (step 5). The model should be flexible enough to perform all kinds of scenario studies and sensitivity analyses as to enable step 5, i.e. analysis and evaluation of new strategies.

New strategies (for example better I&R systems, see Saatkamp, 1996) can lead to better eradication programs which will affect the number of secondary outbreaks and the economic consequences. New preventive programs could affect the number of primary outbreaks. This is symbolized in Figure 2 with the arrows going from 'new strategies' towards the other phases (there is no arrow from 'new strategies' towards 'outbreak in contact region', because outbreaks in contact regions are considered to be part of the exogenous world). In this way the approach integrates the various phases of disease outbreaks and management planning.

Outline of the model

Properties

As shown in Figure 2, the problem of outbreaks of contagious diseases can be divided into several subproblems, which can all form a separate module of an integrated modelling approach. A model consisting of modules is easier to build, to adapt to new situations and to maintain and will also enhance the flexibility of the model. According to Kleijnen (1995), modular programming will also ease the verification of the model.

Various types of models are available and applied in the field of Animal Health Economics (Dijkhuizen, 1988). A choice has to be made on three fundamental properties of the model: static or dynamic, stochastic or deterministic, and optimization or simulation. The nature of the problem, as shown in the flowchart in Figure 2, is a sequence of events, e.g. a primary outbreak comes before a secondary one. Thus, a dynamic approach which contains time as an explicit variable is needed to describe the problem. A deterministic approach means that the outcome of an event can be derived assuming certainty about input values and relationships. Although historical data are not widely available, as stated before, it will be clear that an outbreak can vary in its duration, in the number of secondary outbreaks after a primary outbreak, etc. Monte Carlo simulation (i.e. stochastic modelling) will provide the user not only with the expected value but also with the expected variation of the results. Variance is an important piece of information for decision makers (risk management), who can use it to adapt strategies according to their risk attitude. Risk averse decision makers will especially be interested in the negative side of the outcome distribution (what happens if it comes to the worst) while others may put more emphasis on the reverse side.

An optimization model determines the optimum solution given the objective function and restrictions (Dijkhuizen, 1988). Simulation calculates the effects of pre-defined sets of input variables (scenarios, strategies) and is therefore attractive for exploring strategies that have not been applied yet. Sensitivity analysis, i.e. using different sets of input variables, and comparing the results will give insight into the importance of the various input values. In this way it is possible to discover which input values are most important and need extra attention (additional research).

Thus, to describe the problem realistically and provide the decision maker with the most useful information, the model should be dynamic and stochastic, and results should be obtained by using the simulation technique.

The performance of a model is largely determined by the degree to which its structure mirrors reality. Therefore, the last step in the developmental process should be the verification and validation of the system. Good elaborations on this topic are given by, amongst others, Harrison (1991), Law & Kelton (1991), and Kleijnen (1993). To simplify one might say that verification is aimed at building the system right (building the structure exactly as intended, without any errors in the programming code) where validation refers to building the right system (a right presentation of the real system), which depends on the goal of the model (level of accuracy needed etc.). Without an abundant availability of real-world data (well-documented outbreaks are scarce), validation of the system described in this paper might be a problem, but some possible solutions are given in literature (such as what-if analysis, Kleijnen, 1993).

Modelling uncertainty

The reality of outbreaks of contagious animal diseases contains many aspects about which knowledge is uncertain (e.g. number of outbreaks per year, probability of transporting virus via certain risk factors, etc.). To model this type of uncertainty, several approaches are available. The approaches that have been most widely used and discussed in literature are the use of certainty factors (confirmation theory, Shortliffe & Buchanan, 1975), subjective Bayesian probability theory (Duda *et al.*, 1976), the Dempster- Shafer theory of belief functions (Dempster, 1967; Voorbraak, 1990) and the theory of fuzzy sets (Zadeh, 1988). These techniques were developed mainly to be used in rule-based expert systems, where knowledge is typically expressed in the form of IF-THEN rules (i.e. IF A THEN B), where there is a rule premise (A) and a rule conclusion (B). In general, all techniques try to give the experts consulted a method to express their feelings about the two types of uncertainty that must be addressed in a rule-based expert system, namely rule uncertainty ('does A always lead to B?') and evidence uncertainty ('how likely is A to happen?'). Good descriptions and comparisons of these methods are given by Gold *et al.* (1990), Heatwole & Zhang (1990), and Van der Gaag (1989). Van der Gaag states in her critical review that the models are intuitively attractive but present some theoretical difficulties, especially when multiple evidence has to be combined.

When looking for scientific correctness, the basic concept of mathematical probability is still appealing. This concept has long been the primary approach for dealing with uncertainty. Probability is rooted in the concept that the likelihood of an event can be determined, based on past history of occurrences or based on a good causal model of the system. According to Heatwole & Zhang (1990), mathematical probability is a good approach for dealing with uncertainty when the necessary data, which can be statistical data or objective assessments, are available. They also state that if it is not possible to obtain that type of data, alternative approaches, such as the use of certainty factors (described above), are required. This opinion is not shared by Anderson *et al.* (1977) who state that 'objectivity in science is a myth, in life an impossibility, and in decision making an irrelevance'. According to these authors, subjective probability is the only available concept for decision making. Strong emphasis must be placed, however, on the elicitation of the probabilities in order to get as near as possible to the three basic axioms of probability calculus. These axioms are (1) probabilities cannot lie outside the range of zero to one, (2) the probability that two or more mutually exclusive events will occur is the sum of their respective probabilities, and (3) the probability of the exhaustive (universal) set of events is one.

Input

As outlined in the second paragraph of this paper, literature concerning epidemiology and economic consequences of outbreaks is available (although not abundant). Therefore the most crucial unknowns needed for the model suggested are the risk factors which might be responsible for the introduction of pathogen in a country. The concept of risk factors is well-known. Interviewing experts, organizing brainstorm sessions, for instance, will certainly result in a qualitative list of potential risk factors. Quantifying this information, i.e. assigning probabilities to the risk factors (probability that the risk factor will transport pathogen), is a more complicated task. Anderson *et al.* (1977) emphasize that subjective probability should be consistent with the probability calculus (as described above) and with the decision makers' true beliefs. Several techniques are available to deal with this problem. Depth interviews may seem a logical choice only when a qualitative insight is required. However, according to Selvidge (1975) it is also possible to arrive at a numerical expression of uncertain knowledge during such interviews. Her procedure is especially aimed at cases where the assessors have little or no personal experience with the event being considered and/or have difficulty in distinguishing among very small probability values. Major emphasis is put on splitting the original problem into small parts which should make it easier for the expert to understand what is asked and to assign probabilities. In this way, parts of the procedure could also be useful as an introduction prior to other methods.

A technique already applied in the area of risk factors of contagious animal diseases, is the Delphi method. This method was used in New Zealand to determine the risks involved in FMD (Forbes, 1992) and in the US in a study concerning pseudo rabies (Miller *et al.*, 1994). According to Sackman (1975), Delphi is an attempt to elicit expert opinion in a systematic manner for useful results. Martino (1983) states that the Delphi procedure is a feasible and effective method of obtaining the benefits of group participation in the preparation of a forecast while at the same time minimizing or eliminating most of the problems of committee action. It usually involves iterative questionnaires (several rounds) administered to individual experts (by mail) in a manner guaranteeing the anonymity of their responses. Besides anonymity also controlled feedback is an important characteristic of the Delphi procedure. In each round, group results of the preceding round are provided and the experts are given the opportunity to revise their opinion and/or bring in arguments for or against the group opinion. Sometimes, the questionnaire rounds (by mail) are followed by a group discussion (Forbes, 1992). After this discussion, experts are again given the opportunity to revise their opinion. The aim of the procedure is to reach a certain convergence in opinion about the problem or forecast being considered.

If the risk factors are known, a procedure to rank them might be the method of conjoint analysis. Conjoint analysis was developed in the sixties (Krantz, 1964; Luce & Tukey, 1964; Krantz & Tversky, 1971) and rooted in traditional experimentation. Conjoint analysis developed from a need to analyse the effect of predictor variables that are often qualitatively specified or weakly measured (Hair *et al.*, 1987). The method is widely used in market research to measure consumer preferences in order to develop new products. According to Fishbein (1963), a product or an event can be seen as a composition of attributes. In conjoint analysis, respondents are asked to rank profiles, where a profile represents a product or an event formed by a specific combination of attributes. Attributes are characteristics of a product, e.g. when selecting a car, attributes can be: colour, make, price etc. In the case of contagious animal diseases, the risk factors are the attributes, related to the event 'introduction of virus'. Using regression analysis, the relative importance of the various attributes can be calculated. In this way, the method does not only provide the user with an ordering of the attributes but also gives insight into the distances between them. A major advantage of the method is that it is possible to check up on the consistency of the respondents.

The methods described above all try to help respondents to express their preferences and ideas. Although the methods acknowledge that respondents may feel uncertain about their knowledge, this uncertainty is not expressed in the outcomes of the procedures. A way of expressing uncertainty could be the assessment of Subjective Probability Distributions (SPDs). The mathematical modus of an SPD reflects the best guess of a respondent, the dispersion of the distribution corresponds with the uncertainty about this best guess. Assessing SPDs appears to be a difficult task and several techniques have been developed that support assessors during the specification of their SPDs. These elicitation techniques can be either direct or indirect (characteristics of the SPDs are inferred from the responses of the assessor). Research in this area has been done by, among others, Spetzler & Staël von Holstein (1975). A relatively new method for the elicitation of SPDs has been developed by Van Lenthe (1993). In this method (called ELI) scoring rules have been used to enhance the accuracy of the estimates (SPDs) of the respondents. Van Lenthe's research has resulted in a graphically oriented interactive computer program, called ELI, with a built-in scoring rule. According to its inventor, ELI appears to be a practical and useful method that contributes to relatively reliable and valid SPDs.

The techniques described all contain interesting elements. A combination of several of these methods may be used to quantify the input necessary for the described model.

Discussion and conclusions

Contagious animal diseases formed an interesting topic for researchers from the past, and still do for the present and probably also future, not least because of the considerable economic consequences connected with outbreaks of these diseases. Although many useful studies have been accomplished, there is still need for an integrated model that includes the various aspects of outbreaks and integrates risk components and economic consequences.

Literature shows that various techniques are available that can be used in the development of such a model, none of them being perfect, however. The most appealing technique to base the structure of the model on is mathematical probability, because of its scientific correctness and clear concept. In that case, special emphasis should be given to gathering of input data, which will include the use of expert panels. One of the techniques that can be used when trying to elicit expert knowledge, is the Delphi-method, already used in the area of animal diseases (Forbes, 1992; Miller *et al.*, 1994). However, a good Delphi approach is very time-consuming (several rounds of questionnaires have to be performed) and it is difficult to involve a large number of experts in such a method (Miller used only 8 experts), and keep them involved in each questionnaire round (Forbes started with 28 experts, only 15 of whom completed the second round). Delphi solves the problem of how to reach a kind of an agreement (one answer) when asking different people the same question, minimizing the influence they might have on one another. It does not, however, give any clues about how the question has to be framed.

Promising techniques which give more grip concerning framing of questions are conjoint analysis and eliciting Subjective Probability Distributions (SPDs). Conjoint analysis has proved itself in the area of marketing research. Cattin & Wittink (1982) stated that around 1,000 commercial applications were carried out between 1971 and 1981. An important advantage of the technique over other methods is the possibility of checking up on consistency and reliability of respondents. Elicitation of SPDs is interesting because it allows respondents to express uncertainty about an answer. So far, both conjoint analysis and eliciting SPDs have been used mainly in the area of marketing research. However, in studying their possibilities and limitations, there seem to be no constraints for the use in other fields as well.

It can be concluded that several promising techniques for eliciting expert knowledge are already available. The best method might be an eclectic approach. More research is needed to adapt the methods to the use in the field of animal diseases and to develop the best combination. However, absolute values for the probabilities concerned with the potential transport of pathogen by risk factors will be hard to estimate, because these probabilities are expected to be very small. Moreover, according to Davis and Olson (1985), lack of understanding statistical analysis can heavily bias direct questions on probabilities. Therefore the elicitation of relative values might result in more reliable values, which implies that the resulting model will have its use mainly in comparing situations (i.e. in ranking strategies).

The use of expert panels will provide estimates for input variables for which no historical or experimental data are available. It will be hard (if not impossible) to judge if these estimates are close to the real values. However, until historical data and/or experimental research are able to provide better results, estimates based on expert knowledge will be the best information there is. In all cases, sensitivity analysis should be an important feature of the proposed model. Not only to enable the users (decision makers) to evaluate consequences of various strategies but also to evaluate the impact of uncertain input variables, which will help to guide efficient planning of further research efforts. It must be emphasized that a model will never be a perfect representation of reality, especially not if part of the input is based on estimated values. Therefore, models will never be more than a (hopefully useful) tool to aid decision makers. The final decision will always be the responsibility of the decision makers themselves.

To conclude with, because of specialization and increasing international trade of livestock and livestock products, prevention and eradication of contagious animal diseases have become a matter of national and international importance. Decision makers are operating at 'high' levels and often lack information to foresee all consequences of their decisions for all parts of the production chain. An integrated approach, as suggested in this paper, will enable a better insight and thus be beneficial to the decision making process.

Several elements of the approach suggested have already been subject of extensive research. Now it is time to combine these elements into one model. Research is under way to develop and test such a model.

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