Risk and economics of disease introduction into dairy farms

Gerdien van Schaik

Stellingen

1. Een bedrijf dat zorgt dat het geen directe diercontacten met ander rundvee heeft en bezoekers bedrijfskleding en laarzen aan laat trekken voor het betreden van de stal verkleint de kans op insleep van infectieziekten aanzienlijk. *(Dit proefschrift)*

2. Een meer gesloten bedrijfsvoering is geen belemmering voor het weiden van rundvee, mits er tenminste zes meter afstand met ander rundvee is en er geen contact is doordat er vee uitbreekt. *(Dit proefschrift)*

3. De rentabiliteit van een gesloten bedrijfsvoering stijgt naarmate een bedrijf (al) vrij is van meer infectieziekten. *(Dit proefschrift)*

4. De grootste verdienste van het beslissingsondersteunende model beschreven in dit proefschrift is dat het veehouders en hun adviseurs bewust maakt van de risicofactoren voor insleep van infectieziekten en het een discussie over een meer gesloten bedrijf getalsmatig ondersteunt. *(Dit proefschrift)*

5. Een meer gesloten bedrijf (zoals omschreven in stelling 1) zou de basis moeten zijn van een geïntegreerde, preventieve benadering van infectieziekten.

6. De Gezondheidsdienst voor Dieren beschikt over een rijke bron van gegevens, die nog niet optimaal voor onderzoek wordt benut.

7. Degene die een dataset analyseert weet beter welke combinatie van variabelen in het model van belang zijn dan de betrouwbaarheidstoetsen.

8. Je eigen morele normen en waarden kun je niet veranderen, wel kun je morele waarden van andere culturen leren kennen en accepteren dat er verschillen zijn.

9. Luie mensen krijgen in ieder geval geen RSI (= Repetitive Strain Injuries). *(hoogleraar beroepsziekten M. Frings-Dresen, Volkskrant 16 maart 2000)*

10. De gezondheid en productiviteit van een promotie-onderzoeker worden verhoogd door regelmatig, liefst fysiek actieve vakanties te nemen en vakantie nemen zou gestimuleerd moeten worden.

11. Bij echte liefde is de kleinste afstand te groot en de grootste afstand overbrugbaar.

Stellingen behorende bij het proefschrift 'Risk and economics of disease introduction into dairy farms'. Gerdien van Schaik, Wageningen, 16 juni 2000.

Risk and economics of disease introduction into dairy farms

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Risk and economics of disease introduction into dairy farms

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Abstract

Risk and economics of disease introduction into dairy farms.
Risico en economie van insleep van ziekten op melkveebedrijven.
Van Schaik, G., 2000.

A well closed farming system will enhance the success of disease eradication programs, because introduction or reintroduction of infectious diseases are less likely. The economic implications of a more closed farming system will not always been obvious for farmers. The management decisions need to be made for different parts of the farm and are farm-specific. The objective of the study was to obtain input for and to develop an on-farm decisions support model to calculate the economic consequences of a more closed farming system. The input was based on IBR, since there were numerous data on this disease, but a more closed farming system will prevent introduction of other diseases as well (i.e. BVDV, *L. hardjo*, and *S. dublin*). Direct animal contacts such as purchase of cattle, participating in cattle shows, and cattle that breach or escape and mingle with other cattle were found to be important risk factors for introduction of BHV1. Furthermore, the use of protective farm clothing was found to be an important preventive factor. The effect of a BHV1 outbreak on milk production was estimated with a random effect model. An outbreak of BHV1 on a BHV1-free farm, caused limited milk production losses of on average 39 kg per cow during the outbreak, but the variability was high (95% CI 1-77 kg). Nine percent of Dutch BHV1-free dairy farms that were also at risk for BVDV, *L. hardjo* and/or *S. dublin* had one introduction per year of one of these four diseases. All these results were incorporated in the static, deterministic economic model. The management measures to reduce the probability of introduction of BHV1, the costs of these measures, and the risk reduction of these measures were obtained from other sources. Costs were calculated by using partial budgeting. The model was verified and partly validated and a sensitivity analysis was carried out to obtain insight into the model behaviour. A hypothetical 55-cow dairy farm that refrained from purchasing cattle, provided protective clothing to professional visitors and a temporary worker, and placed a double fence on six ha. of land to prevent over the fence contacts, had to spend Dfl. 4495 in five years. The probability of disease introduction was decreased by 74%. The avoided losses for disease introduction amounted to Dfl. 7033 over five years. The benefit of becoming more closed for this hypothetical farm was Dfl. 2538. The implementation of a more closed system will be profitable for most farms. The profitability will increase when a farm is at risk for more diseases, but will decrease when farms are limited in their facilities to rear replacement heifers or when a large amount of pasture adjoins pasture of other cattle farms.

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Contents

Chapter 1

General introduction

1.1 Introduction

The adoption of the Agreement on the Application of Sanitary and Phytosanitary measures (SPS agreement) of the World Trade Organisation (WTO) in 1994 has markedly changed the rules of international trade in animals and animal products (Marabelli et al., 1999). Governments are allowed trade restrictions based on health status to ensure food safety and animal health protection. Trade restrictions can be avoided by a high health status relative to other countries. In the European Union (EU) it was decided to set high standards and to follow a strategy of non-vaccination for most highly contagious animal diseases (Horst et al., 1999).

Dutch agriculture is characterised by an intensive animal production system. In the past decades the concentration of animals as well as the number of national and international contacts (e.g. live import or export of cattle) have increased considerably (Nagel, 1995). Dutch animal production strongly depends on international markets and together with the favourable geographic situation of the country this results in major import and export of animals and animal products, putting strong pressure on a stable health status (Tazelaar and Gerats, 1995; Horst et al., 1996). The Netherlands aims at a higher animal health status by implementing disease eradication programs. The Netherlands is certified for list A-diseases of the Office International des Epizooties (OIE) and is focusing more on the eradication of list B-diseases. List A-diseases are transmissible diseases, which have the potential for a very serious and rapid spread, irrespective of national borders, which have a serious socio-economic or public health consequence, and which are of major importance for international trade of animals or animal products. Examples of list A-diseases are foot-and-mouth disease (FMD) or rinderpest. List B-diseases are transmissible diseases, which are considered to be of socio-economic and/or public health importance within countries, and which are significant in international trade of animals and animal products. Examples of list B-diseases are infectious bovine rhinotracheitis (IBR), leptospirosis, and paratuberculosis.

For the Netherlands an important pathogen is Bovine Herpesvirus type 1 (BHV1). Several countries in the EU are free of this virus and hence they establish export restrictions (Vonk Noordegraaf et al., 1998). BHV1 causes the disease called IBR as well as infectious pustular vulvovaginitis (IPV). At first introduction in the Netherlands in the 70s, BHV1 caused severe clinical signs. However, in the early 80s outbreaks became subclinical. Approximately 55% of the dairy farms and 40% of the cattle were seropositive for BHV1 in 1996. Approximately 17% of the farms vaccinated against BHV1 at that time and these seropositive cows could not be distinguished from infected cows (Van Wuijckhuise et al., 1997). One of the tools to improve animal health is certification of disease free animals for national and international trade. In 1998 a compulsory eradication program for BHV1 was started in the Netherlands (Vonk Noordegraaf et al., 1998). In 1999 already one third of the cattle farms were certified

BHV1-free. Furthermore, the compulsory eradication of *Leptospira interrogans serovar hardjo* (*L. hardjo*) is well on its way, and voluntary eradication programs for Bovine Viral Diarrhoea Virus (BVDV) and *Salmonella enterica subsp. enterica serotype Dublin* (*S. dublin*) started in 1999 and 2000 respectively.

In recent years, several eradication programs were also implemented in other countries for BHV1, BVDV, *L. hardjo* and *S. dublin*. BHV1 has successfully been eradicated in Denmark, Austria and Switzerland (Straub, 1991). In Shetland BVDV had already been eradicated and the Scandinavian countries are well on their way towards eradication (Lindberg and Alenius, 1999). In Finland several salmonellosis species were successfully eradicated (Aho et al., 1998). The threat of trade restrictions forces other countries to obtain a higher health status with respect to infectious diseases as well (Martineau et al., 1982). In most countries, the responsibility for eradication of non-list A-diseases is at the farm level, implying that individual farmers are responsible for their animals' health. For a successful eradication program farms should remain free of infectious diseases and this can be ensured by a more closed farming system.

1.2 Objectives of the study

The goal of the thesis was to obtain input for and construct a model to calculate the costs and benefits of a more closed system for dairy farms. First, the potential benefits and perception of farmers and their advisers of a more closed farm were investigated. The second and third objectives were to obtain input for the economic model. The input for the model was based on IBR, since there were numerous data on this disease. However, a more closed farming system may prevent introduction of other diseases as well (e.g. BVDV, *L. hardjo* and *S. dublin*) and can be a good starting point for eradication of these infectious diseases. The last objective was to create a simplified economic model to calculate the costs and benefits of a more closed farming system. The model was developed to function as a tool to support farmers in their on-farm decisions about implementing a more closed farming system.

1.3 Some background on risk and economics of disease introduction into dairy farms

A dairy farm cannot be closed completely; there are always necessary contacts with the outside world, through veterinarians, AI-technicians, and cattle grazing outside. In this thesis a more closed farming system was defined as a farm that minimises the risk of direct contact with cattle from other farms. Secondly, the farmer obliges professional visitors (e.g. veterinarians, AI-technicians, cattle traders) to put on protective farm clothing (coveralls or overcoats and boots) before handling cattle. In this thesis professional visitors are visitors that enter the barn and come into contact with cattle (e.g. veterinarians, AI-technicians, cattle traders). Protective farm clothing is defined as coveralls or overcoats and boots that are provided by the farmer before handling cattle. A sanitary barrier is a covered area separated from the animal area of the cattle barn, in which visitors can change into protective farm clothing. A sanitary barrier has a "dirty side", where visitors change clothing and a "clean side", where visitors wear protective clothing and can enter the barn.

In order to obtain a more closed farming system farmers need to be made aware of how diseases are introduced into the herd. Bennett (1991) found that only 22% of the farmers were taking action to prevent or control disease, while 75% of those farms were already suspected of having been infected with *L. hardjo*. Farmers will be more likely to implement a closed farming system when the economic value is quantified and attractive. The potential benefits of a closed farm and the perception of the risk factors for introduction of diseases need to be investigated to verify whether a more closed farming system is profitable and supported by farmers and their advisers.

Many studies have been carried out to qualify and quantify possible risk factors for introduction and spread of infectious diseases. However, little research has been done on changing the system at dairy farms as a whole to a more closed farming system. Some recent studies support the importance of such a system to prevent introduction of BHV1, BVDV, *L. hardjo* and *S. dublin*. Trueman et al. (1996) and McDonough et al. (1999) found purchase of cattle and neighbourhood contacts to be risk factors for introduction of *S. dublin*. For *L. hardjo* Pritchard et al. (1989) report that risk factors for infection are purchase of cattle, river access, sheep grazed with cows, and a hired bull. For BHV1 risk factors quantified by Van Wuijckhuise et al. (1997) were herd type, herd density, herd size, and purchase of animals. These risk factors were also reported by Wentink et al. (1993). Houe (1999) gives an extensive review on the possible risk factors for introduction of BVDV. Valle et al. (1999) conducted a study in which risk factors for BVD-seropositive farms were quantified. Purchase of animals, use of common pasture, and herd to herd contacts over pasture fences were found to be risk factors for BVDV.

From these studies it could be concluded that a more closed farm should reduce or eliminate the risk of the most important risk factors, first direct and lengthy animal contacts, followed by contacts with persons or animal transport vehicles, animal products and transmission by feed, vermin or air. Several surveys were conducted to investigate how many risky contacts Dutch dairy farms had. Surveys of the Animal Health Service (GD) in 1995 and the Dutch Farmers Union (LTO) in 1998 showed that 45-55 percent of the Dutch dairy farms had purchased cattle in the preceding three years. Another study showed that the number of contacts of the farm with professional visitors and their vehicles was large (Nielen et al., 1996). Dutch dairy farms seemed to have an open farm structure. However, the success of most eradication programs will depend on how much risk a farmer takes in his/her management.

Specific pathogen free herds (SPF) are well-known in pig and poultry production (Kuiper and Martens et al., 1994). By eradicating one or more infectious diseases a farm becomes specific pathogen free. The SPF farms clearly have better technical and economic results (Kuiper and Martens et al., 1994) and this may also be expected in dairy herds. However, an SPF herd is susceptible to infectious diseases and therefore the farm has to adapt its management to prevent introduction of diseases and economic losses due to of introduction. In intensive animal production systems (such as in pigs and poultry) a closed farming system is more common practice than in dairy farming. All-in-all-out systems ensure that the animals do not come into direct contact with animals from other pens or farms. Visitors often have to go through a sanitary barrier and put on protective farm clothing or even take a shower before entering the barns (Kuiper and Martens, 1994). The threat of infectious diseases such as Classical Swine Fever (CSF) in pigs, Newcastle Disease in poultry, and foot-and-mouth disease (FMD) in both swine and cattle has forced the farmers to adopt a more closed system. Introductions of these infectious diseases are disastrous, because the farm will be eradicated (Horst et al., 1999). Introduction of other diseases that do not result in eradication can also cause considerable economic losses as they decrease technical results. The economic losses due to introduction of diseases into intensive systems are therefore obvious and can be very large (Martineau et al., 1982). The economic losses avoided are the potential benefits of a more closed farming system.

In a simulation study of Sørensen et al. (1995) the farms with a risky management had higher losses as results of BVDV than low risk farms. A study conducted by De Verdier Klingenberg et al. (1999) determined that strict closure of a dairy herd (no contacts with cattle from other herds) and eradication of BVDV improved farm results. Numerous other studies show that, notwithstanding the farming system, the presence of BHV1, BVDV, *L. hardjo*, and *S. dublin*, have considerable economic consequences (Houe, 1999; Anderson and Blanchard, 1989; Hage et al., 1998; Bolin and Alt, 1998). A more closed farming system that prevents introduction of these infectious diseases might therefore have considerable economic benefits.

1.4 Outline of the thesis

The first two chapters explore the potential of a more closed system at Dutch dairy farms. Chapter 2 describes an exploratory study of the potential economic benefits of a more closed farming system. In Chapter 3 the risk factors for introduction of BHV1 as perceived by farmers, veterinarians and AI-technicians were investigated by means of a conjoint analysis.

The next two chapters deal with the risk factors for the presence of BHV1 at dairy farms. The information for Chapters 4 and 5 was collected through a questionnaire on Dutch dairy farms with a known status for BHV1. In Chapter 4 risk factors for the presence of BHV1 were quantified using logistic regression. In Chapter 5, the rate of seroconversion, divided into new introduction and reactivation of BHV1 was the variable of interest. A sub-sample of the farms and a different technique were used. This technique, called survival analysis, was compared with logistic regression.

For the Chapters 6, 7 and 8 a new data set was collected on dairy farms with a certified BHV1-free status. Because of the certificate these farms were restricted with respect to risky contacts, such as purchase of cattle with an unknown BHV1 status. Risk factors for introduction of BHV1 into these farms are described in Chapter 6. In Chapter 7 two objectives were investigated. The first objective was to quantify the losses in milk production after an outbreak of BHV1 at certified BHV1-free farms. The second objective was to find the most appropriate model to quantify the effect of disease on milk production. Chapter 8 describes the probability and costs of introduction of infectious diseases and a more closed system at the farms under study.

In Chapter 9 all variables from the previous chapters were integrated into one overall computer model with which the costs and benefits of specific management measures can be calculated. The model and its outcome, the profitability of a more closed system at dairy farms, are discussed.

Chapter 10 is a summarising discussion on the techniques used and the results obtained. The possibility and economic attractiveness of a more closed farming system to prevent introduction of infectious diseases are discussed and recommendations for farmers and future research are given.

References

Aho, R., Nauholz, H., Hankonen, P., Nyberg, M., and Tirkkonen, T., 1998. The time required for the elimination of bovine salmonella infection. In: Caple, I.W. (ed) *Proceedings of the XX World Association for Buiatrics Congress*, Sydney, July 1998: 875-877.

Anderson, M. and Blanchard, P., 1989. The clinical syndromes caused by Salmonella infection. *Veterinary Medicine* 84: 816-819.

Bennett, R.M., 1991. A survey of dairy farmers decisions concerning the control of Leptospirosis. *The Veterinary Record* 129: 118.

Bolin, C.A. and Alt, D.P. 1989. Clinical signs, diagnosis, and prevention of bovine leptospirosis. In: Caple, I.W. (ed) *Proceedings of the XX World Association for Buiatrics Congress*, Syndey, July 1998:899-904.

De Verdier Klingenberg, K., Vagsholm, I., and Alenius, S., 1999. Incidence of diarrhea among calves after strict closure and eradication of Bovine viral diarrhea virus infection in a dairy herd. *Journal of the American Veterinary Medical Association* 214: 1824-1828.

Hage, J.J., Schukken, Y.H., Dijkstra, T., Barkema, H.W., van Valkengoed, P.H.R. and Wentink, G.H., 1998. Milk production and reproduction during a subclinical bovine herpesvirus 1 infection on a dairy farm. *Preventive Veterinary Medicine* 34:97-106.

Horst, H.S., Dijkhuizen, A.A., Huirne, R.B.M., and De Leeuw, P.W., 1996. Introduction of contagious animal diseases into the Netherlands: Elicitation of experts opinions'. *Livestock Production Science* 53: 253-264.

Horst, H.S., Meuwissen, M.P.M., Smak, J.A., and Van der Meijs, C.C.J.M., 1999. The involvement of the agriculture industry and government in animal disease emergencies and the funding of compensation in Western Europe. *Revue Scientifique et Technique* 18: 30-37.

Houe, H., 1999. Epidemiological features and economical importance of bovine virus diarrhea virus (BVDV) infections. *Veterinary Microbiology* 64: 89-107

Kuiper, C.J. and Martens, M.R.T.M., 1994. Specific pathogen free health programs. *Tijdschrift voor Diergeneeskunde* 119: 390-393.

Lindberg, A.L.E., and Alenius, S, 1999. Principles for edication of bovine viral diarrhea virus (BVDV) infections in cattle populations. *Veterinary Microbiology* 64: 197-222.

Marabelli, R., Ferri, G., and Bellini, S., 1999. Management of animal health emergencies: general principles and legal and international obligations. *Revue Scientifique et Technique* 18: 21-29.

Martineau, G.P., Broes, A., and Martineau-Doize, B., 1982. Application and limitations of health schemes for pig herds and their economic effect in meat production. *Annales de Medicine Veterinaire* 126, 4: 279-314.

McDonough, P.L., D. Fogelman, A., Shin, S.J., Brunner, M.A. and Lein, D.L., 1999. Salmonella enterica serotype Dublin infection: on emerging infectious disease for the northeastern United States. *Journal of Clinical Microbiology* 37, 8: 2418-2427.

Nagel, R., 1995. Basic figures on livestock demography and trading pattern in the Community. In: Animal health and related problems in densely populated livestock areas of the Community. *Proceedings of a workshop of the European Commission*, A.A. Dijkhuizen and G. Davies (Eds), Brussels, 22-23 November 1994: 7-18.

Nielen, M., Jalvingh, A.W., Horst, H.S., Dijkhuizen, A.A., Maurice, H., Schut, B.H., Van Wuijckhuise, L.A., and De Jong, M.F., 1996. Quantification of contacts between Dutch farms to assess the potential risk of foot-and-mouth disease spread. *Preventive Veterinary Medicine* 28, 3: 143-158.

Pritchard, D.G., Allsup, T.N., Pennycott, T.W., Palmer, N.M.A., Woolley, J.C., and Richards, M.S., 1989. Analysis of risk factors for infection of cattle herds with *leptospira interrogans serovar hardjo*. In: Rowlands, G.J. (ed.), *Proceedings of a meeting of the Society for Veterinary Epidemiology and Preventive Medicine*. University of Exeter, 130-138.

Sørensen, J.T., Enevoldsen, C., and Houe, H., 1995. A stochastic model for simulation of the economic consequences of bovine virus diarrhea virus infection in a dairy herd. *Preventive Veterinary Medicine* 23: 215 – 227.

Straub, O.C., 1991. BHV1 infections: relevance and spread in Europe. *Compendium of Immunology and Microbiology of Infectious Diseases* 14: 175-186.

Tazelaar, R.J. and Gerats, G.E., 1995. Basic figures on livestock demography and trading pattern in the Community. In: Animal health and related problems in densely populated livestock areas of the Community. *Proceedings of a workshop of the European Commission*, A.A. Dijkhuizen and G. Davies (eds), Brussels, 22-23 November 1994: 191-203.

Trueman, K.F., Thomas, R.J., MacKenzie, A.R., Eaves, L.E., and Duffy, P.F., 1996. Salmonella Dublin infection in Queensland dairy cattle. *Australian Veterinary Journal* 74, 5: 367-369.

Valle, P.S., Martin, S.W., Tremblay, R., and Bateman, K., 1999. Factors associated with being a bovine-virus diarrhea (BVD) seropositive dairy herd in the More and Romsdal County of Norway. *Preventive Veterinary Medicine* 11, 40(3-4): 165-177.

Van Wuijckhuise, L., Bosch, J., Franken, P., De Wit, J., Frankena, K., and Elbers, A., 1997. Some epidemiological characteristics of bovine herpesvirus 1 (BHV1) infections as determined by bulkmilk testing of all Dutch dairy herds. *Epidemiologie et Sante Animale*, special issue; 31-32;11.13.1-3

Vonk Noordegraaf, A., Buijtels, J.A.A.M., Dijkhuizen, A.A., Franken, P., Stegeman, J.A., and Verhoeff, J., 1998. An epidemiological and economic simulation model to evaluate the spread and control of infectious bovine rhinotracheitis in the Netherlands. *Preventive Veterinary Medicine* 36: 219-238.

Wentink, G.H., Van Oirschot, J.T., and Verhoeff, J., 1993. Risk of infection with bovine Herpesvirus 1 (BHV1): A review. *Veterinary Quarterly* 15: 30-33.

Chapter 2

Exploratory study on the economic value of a closed farming system on Dutch dairy farms

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Abstract

A closed farming system may prevent introduction of infectious diseases on dairy farms and can be a good starting point for eradication of these diseases. In order to obtain a closed farming system farmers need to be made aware of how these diseases are introduced into the herd. Farmers will be more likely to implement a closed farming system when the economic value is quantified and attractive.

An exploratory study was carried out to investigate the technical and economic results of closed dairy farms. Farms that purchased cattle and/or shared pasture (defined as 'open' farms in this case) differ in technical results from farms that did not ('closed' farms). The results of the discriminant analysis showed that the 'closed' farms incurred lower costs for veterinary services, had a lower average age at first calving and a higher birth rate per 100 dairy cows. A linear regression analysis was carried out to investigate the influence of the farming system on economic farm performance. Being 'closed' was found to have a positive influence of £0.311 per 100 kg of milk on net profit, which equals about £25 per cow per year or 5% of the typical net return to labour and management.

2.1 Introduction

A major aim of the European Union (EU) livestock policy is to improve the health status of farm animals in the member states. Preventive herd health control at farm level is considered the major tool to bring about this improvement. National borders are replaced by borders around the individual farm implying that individual farmers are responsible for the animal health status. Farmers need to be aware of the risks and management opportunities in order to maintain or improve animal health status on the farm (Julicher et al., 1993).

Dutch agriculture is characterised by an intensive animal production system. In the past decades the concentration of animals as well as the number of national and international contacts (e.g. life import or export of cattle) have increased considerably (Nagel, 1995). Dutch animal production strongly depends on international markets and together with the favourable geographic situation of the country this results in major import and export of animals and animal products, putting strong pressure on maintaining a good health status (Tazelaar and Gerats, 1995).

Statistics for 1994/1995 show that there are approximately 1.7 million dairy cows on 32,000 specialised dairy farms in the Netherlands (Agricultural Economics Research Institute, 1996). The farms have, on average, 53 cows and 31 hectares of land with an average milk production

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1 £1 = Dfl 2.80 (November 1996)

of 6954 kg per cow per year. Surplus cattle are sold as calf, heifer or fattening cattle. About 50,000 heads of cattle are sold for live export annually.
According to the Dutch extension services the major routes through which an infectious agent can be introduced on a farm are (Koole, 1995):

- Contact with other dairy cows (e.g. cows purchased, cows on cattle shows)
- Contact with other animal species that are potential carriers of the disease (e.g. sheep, goats, rats, dogs)
- Transmission by humans (e.g. visitors, veterinarians)
- Transmission by machinery (e.g. cattle trucks, manure applicators, tools)
- Transmission by foodstuff or water (e.g. ditch water)
- Transmission by air

Research was carried out to investigate the number and kind of contacts Dutch dairy, pig and mixed farms have (Nielen et al., 1996). When risky contacts, such as buying cattle and visits of a veterinarian, and less risky contacts (e.g. feed transport, dairy tanker, social human contacts, et cetera) were combined, cattle farms had a median of 6.9 contacts per day. A survey of the Animal Health Service in the northern provinces of the Netherlands showed that 55% of the dairy farms purchased cows in the preceding year (1994) (Benedictus, pers. comm.). Direct and lengthy animal contacts are the most important risk factors, followed by contacts with persons or animal transport vehicles, animal products and transmission by feed, vermin or air (Wentink et al., 1993; Koole, 1995; Horst et al., 1996). The most usual way of BHV1 transmission between farms is introduction of latently infected animals on a farm (Msolla et al., 1981; Pastoret et al., 1984). To obtain a closed farming system farmers need to be made aware of the risk of introduction of infectious diseases on the farm. Farmers will be more likely to implement a closed farming system when they are aware of the economic value of such a system. However, the economic value of a stable animal health status and a closed farming system has not yet been quantified.
The present study explores the economic values of adaptations in management (i.e. a closed system) on dairy farms to prevent introduction of diseases and improve the health status on the farm. According to the advice of the extension services (i.e. Animal Health Service and National Reference Centre for Livestock Production) a closed farming system may prevent introduction of e.g. BHV1, BVDV, Leptospirosis, Paratuberculosis, and Salmonella on a farm and can be a good starting point for eradication of these infectious diseases. Further study will be necessary to reveal the epidemiological characteristics of a closed farming system. The reported study evaluates the advice of the extension services on economic characteristics.

2.2 Materials and methods

An exploratory study was carried out to investigate the technical and economic results on open and closed dairy farms. Data were derived from an accounting system for Dutch dairy farms (DELAR) and cover a two-year period. DELAR is used on approximately 2500 farms and provides the farmer with information on average animal performance (milk production and cattle credits), land use (forage production and some other crops), fodder consumption (concentrates, forage and milk products) and remaining costs (fertilisation and contract work). The available dataset contained data of 1485 farms of two one-year time periods ('91/'92 and '92/'93).

The farms were grouped by several variables present in the accounting system, namely income from or costs of sharing pasture, number of animals purchased, and number of animals reared for or on other farms. If a farm did not any such thing (share pasture, rear animals for or on other farms, or purchase cattle), it was defined as a 'closed' farm, otherwise the farm was defined 'open'.

To gain insight into which variables account for the differences between open and more closed farms, multivariable analyses (discriminant analysis and regression analysis) were carried out. Discriminant analysis is a statistical technique for studying the differences between two or more groups of objects with respect to several variables simultaneously (Klecka, 1980). In our study, the farms (data cases) were divided into two groups (open and closed) according to several discriminating variables (e.g. purchase of cattle and sharing pasture for cattle). Discriminant analysis with the CANDISC procedure (SAS,1988) results in a discriminant function consisting of independent variables (Klecka, 1980). The variables of this function influence the difference between the 'open' and 'closed' farms. The discriminant analysis was carried out on half of the farms in the dataset. The other half was used for the linear regression analysis with the REG procedure (SAS, 1988) to predict economic farm results. A forward stepwise selection procedure at $p<0.10$ was used to select the variables for the model. The variables which were highly correlated ($r>0.50$) were excluded from the model. Only variables which remained significant at $p<0.05$ were included in the final model.

2.3 Results

2.3.1 *Grouping variables*

In the two-year period, 356 (24%) of the 1485 farms did not buy cattle nor shared pasture. The remaining 1129 farms (76%) could not be called closed in these respects in one or both years. Table 1 provides the average figures for the aspects according to which a farm was defined 'open'.

Table 1: Averages for 'open' farms (n=1129) of variables according to which a farm is defined 'open'.

	Mean	Sd	Min	Max
Costs of sharing pasture (£)[a, b]	559.3	1242.9	0	20240.4
Returns from sharing pasture (£)[b]	168.1	741.2	0	10714.3
# cattle purchased	2.9	4.4	0	33.0
# animals shared elsewhere	4.4	7.7	0	57.2
# animals shared on the farm	0.1	1.1	0	18.2

[a] £1 = Dfl 2.80 (November 1996)

[b] Costs or returns are figures derived from the accounting system. A farmer incurred costs for having cattle grazed on other farms or got paid when cattle from someone else were grazed on his farm.

On average, only small numbers of animals are moved per farm per year (Table 1). A farm on average purchased 2.9 cows per year and shared 4.4 cows elsewhere. The low mean value (2.9) and standard deviation (4.4) and the high maximum value (33.0) of e.g. purchase of cattle show that only a few of the 'open' farms purchased a high number of cattle.

2.3.2 Discriminant analysis

Table 2 shows all variables of the discriminant analysis which significantly influenced ($p<0.05$) the difference between the 'open' and 'closed' farms. The higher the value of the coefficient, the stronger the variable influences the differences between 'open' and 'closed' farms. A variable with a positive value means that the variable is the highest on the 'open' farms. A variable with a negative value is the highest on the 'closed' farms. The most important variable according to Table 2 is 'percentage of replacements of cows' (0.80) which is higher on the 'open' farms. The second important variable is 'births per 100 cows' (-0.58) which is higher on the 'closed' farms. The value of the coefficient of the other variables in Table 2 becomes smaller, meaning the impact of those variables on the difference between 'open' and 'closed' farms is less. At the bottom of the list is 'veterinary costs per cow', a variable with a relatively low impact on the difference (0.07) but nevertheless is significantly higher on the 'open' farms.

2.3.3 Regression analysis

A regression analysis was carried out to predict the net profit per 100 kg of milk. A stepwise selection procedure on the remaining half of the farms in the dataset (741) resulted in the linear regression model without intercept ($R^2 = 0.99$; Root MSE = 239.7; $p < 0.05$) shown in Table 3.

Table 2: Variables that significantly influenced ($p<0.05$) the difference between 'open' and 'closed' farms.

Variables	Contribution to the difference between 'open' and 'closed' farms
Percentage of replacements of cows	0.80
# births / 100 cows	-0.58
Fat content in milk	-0.36
Net profit / hectare	0.29
Percentage of youngstock	-0.27
Kg of phosphor / hectare	-0.25
Average age at first calving	0.24
Kg of nitrogen / hectare	-0.23
Roughage costs / cow	0.20
# dead cows	-0.20
Irrigation of pasture	-0.19
Automatic concentrates feeding / forage mixer	-0.10
Veterinary costs / cow	0.07
Concentrates costs / cow	0.01

Table 3: Regression on net profit (in £) per 100 kg of milk.

Independent variables*:	Dependent variable: net profit per 100 kg of milk
Protein content in milk	4.76
Fat content in milk	3.30
# cows per hectare	-2.00
Dutch red and white or RHF breed compared with HF	0.39
'Open' farm	-0.31
Automatic concentrates feeding / forage mixer	-0.27
# dead cows	-0.21
# calves dying within 14 days	-0.05
# births / 100 cows	-0.03
Hectares of pasture	-0.03

* All variables in the model are significant at $p<0.05$

RHF = Red Holstein Frisian

HF = Holstein Frisian

The high value of R^2 did not have any meaning in a model without intercept. The price of milk was aproximately £0.27 per kg and the average milk production per cow used in the calculations was 7500 kg. 'Open' farms have a negative influence of almost £0.31 per 100 kg milk on net profit, which equals about £25 per cow per year or 5% of the typical net return to labour and management. Furthermore, protein and fat content in milk, and breed have a positive influence on the net profit per 100 kg of milk. The number of cows per hectare, the presence of automatic concentrates feeding or a forage mixer, the number of dead calves and cows, and the number of births per 100 cows all have a negative influence on the net profit per 100 kg of milk. To place the figures in perspective some costs are provided. The price of a milking cow was on average £500 and the price of a hectare of grassland was on average £13.500.

2.4 Discussion and conclusions

Farms that purchased cattle and/or shared pasture ('open' farms) differ in technical results from farms that did not ('closed' farms). The results of the discriminant analysis showed that the 'closed' farms had a higher birth rate per 100 dairy cows, a lower average age at first calving and lower costs for veterinary services. A linear regression analysis was carried out to investigate the influence of the farming system on economic farm performance. Half of the dataset not used in the discriminant analysis was used for the regression analysis. Several variables found in the discriminant analysis influenced economic farm performance considerably(Table 5). An 'open' farm was found to have a negative influence of £0.31 per 100 kg of milk on net profit, which equals about £25 per cow per year or 5% of the typical net return to labour and management of a farmer.

The DELAR program is a tool for accounting dairy farm performance. Therefore, the available datasets limited the possibilities of the analyses. The division in 'open' and 'closed' farms was only based on cattle purchases and sharing pasture. No data were available on other routes of introduction. Other contacts of the farms, such as visiting cattle shows, natural service, visitors on the farm et cetera and the presence of other animal species (pigs, sheep, beef cattle), were not known. Moreover, the grouping in 'open' and 'closed' was only based on two years ('91/'92 and '92/'93). It was not known if the farmer acted the same (did or did not purchase cattle or share pasture) in the preceding years. Causal relations between a closed dairy farming system, animal health, and farm results could also not be derived from these data. No data on management and animal health were available. The negative effect on net profit per 100 kg of milk of an 'open' with respect to a 'closed' farm justifies further research in this respect.

To gain a better understanding of the influence of farming systems on introduction of diseases, animal health status and farm results, besides the role of management, a supplementary study will be carried out. This study will concentrate on animal health and management in relation with a more or less closed farming system and the costs and benefits of such a system. The farms for the study will all have a known disease status for BHV1. Data on the farming system, the degree to which a farm is closed, and management of the farmer especially regarding diseases will be collected by means of a questionnaire. The objective of the study is to see if farms that differ in serologic status for BHV1 differ in risk factors for introduction of diseases, in management regarding animal health status, and in economic results.

References

Agricultural Economics Research Institute (LEI), 1996. LEI publication. The Hague, 172pp. (in Dutch)

Horst, H.S., Huirne, R.B.M. and Dijkhuizen, A.A., 1996. Eliciting the relative importance of risk factors concerning contagious animal diseases using conjoint analysis: A preliminary survey report. *Preventive Veterinary Medicine* 27, 3-4: 183-195.

Julicher, C.H.M., Van Klink, E.G.M., De Peuter, G., Schumer, D.L. and Versteijlen, G.H.J.M., 1993. Final report of the project group "The Future of Animal Health". The Hague, 62 pp. (in Dutch)

Klecka, W.R., 1980. Discriminant analysis. Lewis-Beck, M.S. (ed). Beverly Hills and London, Sage Publications 07-019, 71pp.

Koole, H., 1995. Hygiene for dairy farms. IKC publication. Lelystad, 15pp. (in Dutch)

Msolla, P.M., Wiseman, A. and Selman, I.E., 1981. The prevalence of serum neutralizing antibodies to infectious bovine rhinotracheitis virus in Scotland. *Journal of Hygiene* 86: 209-215.

Nagel, R., 1995. Basic figures on livestock demography and trading pattern in the Community. Animal health and related problems in densely populated livestock areas of the Community. *Proceedings of a workshop of the European Commission*, Dijkhuizen, A.A. and Davies, G. (Eds), Brussels, 22-23 November 1994: 7-18.

Nielen, M., Jalvingh, A.W., Horst, H.S., Dijkhuizen, A.A., Maurice, H., Schut, B.H., Van Wuijckhuise, L.A. and De Jong, M.F., 1996. Quantification of contacts between Dutch farms to assess the potential risk of foot-and-mouth disease spread. *Preventive Veterinary Medicine* 28, 3: 143-158.

Pastoret, P.-P., Thiry, E., Brochier, B., Derboven, G. and Vindevogel, H., 1984. Latent Herpesvirus Infections in Veterinary Medicine. Wittmann, G., Gaskell, R. and Rziha, H.-J. (Eds), Martinus Nijhoff Publishers, The Hague, 211.

SAS/STAT® Users Guide, Release 6.03 Edition (1988) SAS Inst. Inc., Cary, NC, 1028pp.

Tazelaar, R.J. and Gerats, G.E., 1995. Basic figures on livestock demography and trading pattern in the Community. Animal health and related problems in densely populated livestock areas of the Community. *Proceedings of a workshop of the European Commission*, Dijkhuizen, A.A. and Davies, G. (eds), Brussels, 22-23 November 1994: 191-203.

Wentink, G.H., Van Oirschot, J.T. and Verhoeff, J., 1993. Risk of infection with bovine Herpesvirus 1 (BHV1): A review. *Veterinary Quarterly* 15: 30-33.

Chapter 3

Adaptive conjoint analysis to determine perceived risk factors of farmers, veterinarians and AI technicians for introduction of BHV1 to dairy farms.

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Abstract

A study was carried out to determine the possibility of a more-closed farming system for (Dutch) dairy farms. The objective of the study was to provide effective and economically profitable management advice for improving the animal health status of farms. Management measures will only be successfully applied if supported by farmers and their advisers (such as veterinarians). Therefore, the perception of farmers and advisers of the importance of various risk factors for introduction of diseases to a farm was determined by using Bovine Herpesvirus type 1 (BHV1) as an example.

As part of the study, an evening-long workshop was organized and run three times. In total, 49 farmers, veterinarians and AI technicians participated in these workshops. The computerized questionnaire technique was based on Adaptive Conjoint Analysis (ACA). ACA has the advantage that participants can work with a large number of risk factors in a relatively short period of time. Another advantage of ACA (compared with standard questionnaires) is that the answers from each participant can be checked as to consistency with respect to the importance assigned to them. Data from participants with inconsistent responses can be excluded from further analyses. The results of the ACA interview were compared with the risk factors reported in the literature as being associated with BHV1 status (e.g. purchase of cattle, participation in cattle shows) and with farmers' actual management to prevent introduction of diseases.

The workshop participants were all operating in the dairy sector and they seemed well aware of the risk of direct animal contacts for introduction of BHV1. Farmers thought visitors to be more risky than AI technicians and (especially) veterinarians. Farmers who purchased cattle or participated in cattle shows were of the opinion that the risks of direct animal contacts were more important than farmers who were not involved in those practices. Farms that were BHV1-positive (and participated in cattle shows more often) thought the risk of participation smaller than BHV1-negative farms.

3.1 Introduction

In May 1998 a compulsory vaccination program was started to eradicate BHV1 (Bovine Herpesvirus type 1 causing Infectious Bovine Rhinotracheitis (IBR)) in the Netherlands. the Netherlands is a very densely populated livestock area with, on average, almost two cattle farms per km^2 (Van Wuijckhuise et al., 1997). Furthermore, national and international trade in animals has increased considerably (Nagel, 1995), putting strong pressure on maintaining a good health status (Tazelaar and Gerats, 1995). Other contacts (such as visitors or transportation vehicles) are numerous as well on Dutch farms (Nielen et al., 1996, Van Schaik et al., 1998). These contacts can also be a serious threat to maintaining a BHV1-free animal-health status. Eradication of BHV1 will only succeed if farmers increase awareness of the risk of an 'open' farming system and adopt measures to reduce risks. In a more-closed system, the risks of direct animal contacts are minimized and specific measures are taken to prevent introduction of diseases through visitors (e.g. providing protective clothing), materials and machinery (by cleaning and disinfecting procedures). For a successful eradication of BHV1, the progam needs to have support of the farmers and other operators in the dairy sector (such as veterinarians, AI technicians, and traders).

Van Schaik et al. (1998) carried out a case-control study to investigate the risk factors for introduction of BHV1 on dairy farms. That study identified several risk factors which need special attention in an eradication program, such as purchase of cattle, participation in cattle shows and occasional visitors (e.g. neighbors, family, et cetera) and professional visitors (e.g. veterinarians, AI technicians, cattle traders, et cetera). In the study described in the current paper, our objective was to determine the perceptions of farmers, veterinarians and AI technicians of the importance of different risk factors for introduction of BHV1. The relationship between the perception of the farmer and his/her actual management of the risk of infectious disease introduction (derived from the case-control study) was also investigated.

3.2 Materials and methods

3.2.1 The workshops

In September 1996, 65 farmers who had participated in the study by Van Schaik et al. (1998) on risk factors for introduction of BHV1 were invited to an evening-long workshop at the Animal Health Service (an organization in charge of animal diseases and animal health care on national level) . The veterinary practitioners working for the participating farmers and AI technicians operating in the northern provinces of the Netherlands (the area where the farmers in this study came from) were also invited. Twenty-seven farmers, 13 veterinarians and 9 AI technicians participated in the three (identical) workshops. In each workshop, all three groups were represented but individuals attended only one workshop. Each workshop started with a short introduction to the subject and some technical explanations. After the introduction, a short computerized test was carried out to make sure that the participants were familiar with the technique and software. The test was about holiday preferences and was used to accustom the participants to the computer and the program. The test and the questionnaire were designed using ACA software (Sawtooth Software, Evanston, IL) and were fully computer-based. Each participant was provided with a personal computer to work independently from the others. There was no interaction between participants and between participants and workshop facilitators during the data-collection process.

3.2.2 *Adaptive Conjoint Analysis*

ACA was used instead of a paper questionnaire since ACA has several advantages. First, respondents can work with a large number of risk factors in a relatively short period of time. Second, ACA customizes the interview so each respondent is asked in detail only about those risk factors of greatest relevance for him or her. Third, the answers from each participant can be checked for consistency and excluded from further analyses when answers are inconsistent. Furthermore, after completion of the interview the estimated preferences of the respondent are directly available for discussion or analyses. (Metegrano, 1994).

ACA is based on the principles of conjoint analysis, which was originally used in marketing research for the elicitation of consumers' preferences (Green and Srinivasan, 1990). Products or services are thought of as possessing specific levels of defined attributes, and a respondent's preference for a product is modeled as the sum of the respondent's 'utilities' for each of its attribute levels (Metegrano, 1994). Take, for example, consumers' preferences for a car. A car has a color (an attribute) and this color can be red or blue (levels of the attribute). The consumer has a certain preference (utility) for each of the different colors. ACA's main distinguishing characteristic is its adaptive computer administered interview format, which is customized to each respondent. Data are analyzed as the interview progresses so that questions can focus on those areas the respondent indicates as most important. This approach minimizes the number of questions and the time required to complete the survey (Metegrano, 1994).

In the context of risk factors for contagious animal diseases, the basic assumptions were described by Horst et al. (1996a): 1) a risky situation (profile) can be described by a set of attributes (risk factors), and 2) a person's judgement of a situation is based on the level of each attribute (risk factor). The attributes considered in the current experiment were: purchase of cattle, participation in cattle shows, rejected export cattle that returns to the farm, cattle grazing at less than three meters distance of other cattle, visitors, machinery, natural service, secondary farm business, vermin, water and manure. Attributes could have two to five levels, for example, the attribute 'Rejected export cattle' was divided into two levels: 'Rejected export cattle did not return to the farm' and 'Rejected export cattle return to the farm'. The levels of the other attributes are shown in the appendix. Frequency of occurrence was not taken account of in the risk factor (e.g. not the number of cattle purchased). Participants will therefore tend to incorporate their own experience in their perception of risk factor importance.

The questionnaire consisted of two parts: 1) ACA interview about risk factors for introduction of BHV1 to dairy farms, and 2) evaluation of the ACA interview itself. The ACA interview proceeded in a fixed order. First the participants were asked to exclude levels of risk factors they thought not to be important at all for the introduction of BHV1 to dairy farms. Second, the participants were asked to rank the remaining levels of each risk factor to identify the perceived risk of the levels. The level with the highest perceived risk was ranked first and the level with the lowest risk was ranked last. Then, pairs of profiles (each consisting of 2 or 3 risk factors with differences in one or several risk factor levels) were compared and risk perception of each of the participants recorded. Interviews using ACA are performed in an 'intelligent way'; the program adapts the selected profiles according to earlier answers given by the participant in order to maximize the information gain while limiting the number of combinations of profiles to be evaluated. All additional scores provided by the participant were used to update the original risk estimate for a risk factor using an iterative algorithm. At the end, the program constructed a series of customized profiles for each participant. These profiles were ordered by risk perception, from very risky to low risk based on earlier answers of the participant. The internal consistency (correlation) of the participant's responses was assessed by comparing each respondent's expected responses to the customized profiles (as inferred from the utilities from the pairs of profiles part) and the respondent's actual responses (Metegrano, 1994).

The utilities (risk perception) produced by ACA are scaled at the individual-respondent level, using each respondent's risk perception information. When using ACA data with other processing software, the data must first be scaled so that utilities can be compared across participants. The utilities were scaled in such a way that the sum of the utility 'points' across all levels for a respondent was equal to the number of attributes times 100. For details on the method, see Metegrano (1994).

During the last part of the ACA workshop, the participants were asked to evaluate the interview procedure itself. A total of 5 questions were asked about e.g. realism of the profiles, duration, and simplicity. Answers were given as scores from 1 to 7.

Four farmers were excluded from the analyses because their correlation coefficients (a measure of consistency of their responses) was smaller than 0.30. This cut-off value was derived by plotting the number of respondents against the value of the correlation coefficient. Both a correlation smaller than 0.30 or 0.50 could be the cut-off value, these participants seemed to be outliers. The cut-off value of 0.30 was chosen for the analyses and the cut-off value of 0.50 was tested with a sensitivity analysis.

3.2.3 Data analysis

In the analyses, observations were assumed to be independent and that there was no interaction between the levels of different risk factors. As the utilities estimated were not normally distributed, a non-parametric Kruskal-Wallis test at $P \leq 0.05$ (Conover, 1980) was used to investigate whether the perception of the three groups differed or not. Second, the differences in perception of risk factors between two groups were investigated by the Mann-Whitney U-test. Since this was multiple testing of the data the significance level was adjusted by using the Bonferroni test. Three groups were compared and therefore the significance level became 0.05 divided by 3; $P \leq 0.017$ (Thomas et al., 1985). A sensitivity analysis was carried out by excluding all respondents with a correlation coefficient smaller than 0.50 and then reinvestigating the differences in perception using the Kruskal-Wallis test at $P \leq 0.05$. The sensitivity analysis will give insight into the consistency of the data and whether excluding participant with a correlation coefficient smaller than 0.30 was sufficient.

Several risk factors that were reported by Van Schaik et al. (1998) as being associated with possible introduction of BHV1 at a farm were investigated as to their relationship with the utilities of the farmers resulting from the ACA interview. The significance of the relationship between the perception of farmers and their actual farming practices was investigated using the Mann-Whitney U-test at $P \leq 0.10$. This liberal P-value was used since the power of the study is low due to the limited number of participating farmers (23). Furthermore, the main interest of this analysis was to show trends in the relation perception and actual management practices. A two-sided test was used since farmers can realize the importance of a risk factor, but can still be involved in this risky practice. However, farmers might also realize the importance of the risk factor and not practice it. Farming practices were only reported in this paper when the farmers significantly differed in risk perception All analyses were carried out using the non-parametric test procedures in SPSS 6.0 (Norusis, 1993).

3.3 Results

3.3.1 Adaptive Conjoint Analysis

Table 1 shows the median and percentiles of the utilities for all participants. Only the level of the attributes (risk factors) with the highest utility is shown. The risk factors were ranked according to utility.

Rejected export cattle that returns to the farm (median utility=108) and purchase of cattle at a market or sale (without preventive measures, median=105) were perceived to be the most-risky behaviors according to the participants. The median correlation coefficient (measure of consistency) was 0.76 and the median duration of the ACA interview (not including the evaluation) was 38.5 min.

Table 1: The perceived risk factors for introduction of BHV1 to dairy farms for Dutch farmers, veterinarians and AI technicians (n=45).

	Percentile of utilities		
Risk factors	25th	50th	75th
Rejected export cattle return to the farm	90	108	130
Purchase of cattle at a sale or market place; no precautionary measures	89	105	125
Possible nose-to-nose contact with other cattle	69	85	110
Purchase of a bull for natural service from a farmer/trader	71	85	101
Participation in cattle shows	52	70	88
Visitors who don't use protective clothing or boots	43	61	77
Box for clipping claws of cattle	14	35	49
Cattle trucks in the farm yard	11	32	46
Borrowed tools (e.g. cattle shaver, delivery materials)	7	24	39
Cattle at least 3m separated by ditch or fence, no nose-to-nose contacts possible	8	22	35
Hosing machinery/tools down and prohibition of cattle trucks in the farm yard	0	16	36
Manure application by hired mechanisators	0	10	26
Beef cattle that are stabled and/or grazing together with dairy cattle	0	0	0
Sheep/goats which are stabled and/or grazing together with dairy cattle	0	0	0
Rats and mice	0	0	0
Flies	0	0	0
Birds	0	0	0
Dogs and cats	0	0	15

In Table 2, the differences in perception of importance of risk factors for introduction of BHV1 among farmers, veterinarians and AI technicians are shown.

Farmers and AI technicians thought 'rejected export cattle that returns to the farm' to be a less important risk factor than did veterinarians. Veterinarians considered 'purchase of cattle' from unknown sources to be the most important risk factor. Overall, the veterinarians were more extreme in their risk perception and regarded the direct animal contacts as the most important risk factor. The farmers also perceived the direct animal contacts as most important but thought 'machinery' to be more risky than the other groups. The three groups did not significantly differ in correlation and duration of the ACA interview.

A sensitivity analysis was carried out by excluding participants with a correlation coefficient less than 0.50 and redoing the Kruskal-Wallis test. Eight participants were removed; 19 farmers, 12 veterinarians and 6 AI technicians remained for the analysis. The results were almost the same as those shown in Table 2. Only 'cattle trucks in the farmyard' was replaced by 'box for clipping claws of cows'.

Table 2: Medians of the perception of the importance of risk factors stratified on farmers, veterinarians and AI technicians resulting from a Kruskal-Wallis test at P≤ 0.05

Risk factors	Farmers (n=23)	Veterinarians (n=13)	AI technicians (n=9)
Rejected export cattle return to the farm	105	118[c]	79[c]
Purchase of cattle at a sale or market place; no precautionary measures	98[a]	133[a,c]	85[c]
Participation in cattle shows	69	87[c]	61[c]
Cattle trucks in the farmyard	43[b]	27	16[b]
Hosing machinery/tools down and prohibition of cattle trucks in the farm yard	33[a]	1[a]	9
Borrowed tools (e.g. cattle shaver, delivery materials)	17[a]	33[a]	26

[a] Significant difference (Mann-Whitney U-test , P≤ 0.017) between farmers and veterinarians

[b] Significant difference (Mann-Whitney U-test , P≤ 0.017) between farmers and AI technicians

[c] Significant difference (Mann-Whitney U-test , P≤ 0.017) between veterinarians and AI technicians

A comparison was made between the perception of the farmers and their actual management with respect to introduction of infectious diseases. Farms on which the risk factors found in the risk analysis (Van Schaik et al., 1998) were present or absent were compared. Table 3 only contains results of the division for the risk factors with significantly different utilities. A comparison was also made between BHV1-positive and BHV1-negative farms. The BHV1-status of 20 farms was known from the case-control study by Van Schaik et al. (1998).

Table 3: Comparison between the perception of the importance of risk factors by farmers and their actual management practices (Mann-Whitney U-test , P≤ 0.10)

Perception of the importance of risk factors	Median utility		P
	No cattle purchasing farms (n=6)	Cattle purchasing farms (n=17)	
Visitors disinfect their footwear	44	27	0.05
Borrowed tools (e.g. cattle shaver)	0	27	0.03
Purchase of bull for natural service from a farmer/trader	73	94	0.04
	No participation in cattle shows (n=17)	Participation in cattle shows (n=6)	
Manure applicators	0	21	0.08
Rejected export cattle return to the farm	100	120	0.10
Nose-to-nose contact with other cattle	73	112	0.01
	BHV1-negative farms (n=8)	BHV1-positive farms (n=12)	
Participation in cattle shows without a controlled disease status	79	57	0.10

Only farms that did or did not 'purchase cattle' or 'participate in cattle shows' significantly differed in the median utilities of the levels of a number of risk factors. Farms that purchased cattle thought 'visitors who disinfect their footwear' more risky compared with the farms that did not purchase cattle. Furthermore, the farms that purchased cattle considered 'borrowed tools' and 'purchase of a bull' to be more risky than the farms that did not purchase. There was a trend that farmers who participated in cattle shows regarded 'manure applicators', 'rejected export cattle returning to the farm' and 'nose-to-nose contacts' riskier than farmers who did not participate in cattle shows. The BHV1-positive farms (which had according to the study by Van Schaik et al. (1998) 3.5 times greater odds to participate in cattle shows) seemed to perceive this participation to be less risky than the BHV1-negative farms.

3.3.2 *Evaluation of ACA interview*

Table 4: Evaluation scores given by the participants to the Adaptive Conjoint Analysis interview process[a].

Variable	Median evaluation scores			
	Farmers (n=23)	Veterinarians (n=13)	AI technicians (n=9)	Whole group (n=45)
Not interesting (1), interesting (7)	5	5	4	5
Too long (1), not too long (7)	4	5	4	4
Unrealistic (1), realistic (7)	5	5	5	5
Difficult (1), simple (7)	4	5	4	4
Boring (1), entertaining (7)	5	6	4	5

[a] The duration of the evaluation significantly differed between the groups and was 5 minutes for the farmers, 3 minutes for the veterinarians, 6 minutes for the AI technicians and 4 minutes for the whole group. The duration of the evaluation was significantly lower ($P \leq 0.017$) for the veterinarians compared with the other groups.

The high median values of the scores of the whole group show that the overall perception of the ACA interview was good. The veterinarians took less time to complete the evaluation. There were no other significant differences found between the groups with $P \leq 0.017$ adjusted for multiple comparisons.

3.4 Discussion and conclusions

The ACA interview was an easy-to-use tool to obtain the perception of farmers, veterinarians and AI-technicians of the importance of risk factors for introduction of BHV1 to dairy farms. This has also been reported by Horst et al. (1996b) and Stärk et al. (1997) who conducted a similar type of ACA workshops with veterinary experts. Although several farmers, veterinarians and AI technicians were not familiar with using computers, they successfully completed the ACA interview.

The information obtained through ACA can be used as input for a simulation model (Horst et al., 1996a,b; Stärk et al., 1997). It can also be used to find out what the perception of participants about a certain subject is, for instance, to be able to better deal with lacking or inconsistent knowledge in farm advice (e.g. the perceived utility of applying protective clothing to visitors might differ between farmers and veterinarians). In our study the farmers were a self-selected group from a sub-population; they were all participants in the case-control study by Van Schaik et al. (1997). Their knowledge of risk factors was probably slightly better than the knowledge of typical Dutch dairy farmers as a result of their participation in this kind of study, their willingness to participate in the workshop, and their geographical location in the Netherlands. All participants lived in the northern part of the Netherlands, where 30% of all Dutch dairy farms are located (Product Board for Livestock, Meat, and Eggs, 1997). Eradication of BHV1 seemed to be more important to farmers in this area specialized in dairy cattle than elsewhere. The study might therefore result in slightly different perceptions compared with the typical Dutch farmers.

Inconsistency in this interview can occur due to difficulties in understanding the questions and due to a lack of knowledge about the risk factors. The ACA questionnaire was pre-tested with a group of farmers to check whether it was understandable, and was later adjusted according to their comments and suggestions. Inconsistency resulting from poor understanding of the questions should therefore be uncommon. The evaluation also showed that the ACA interview was perceived as quite simple by the participants (Table 4). Only four inconsistent farmers with correlation coefficients of less than 0.30 were initially excluded from the analyses. The remaining correlation coefficients were high (median of 0.76) and did not differ significantly between the groups (Table 2). The ACA interview was time-efficient;. the duration had a median of 39 min (Table 1; minimum = 20 min, and maximum = 52 min).

The limited number of participants relative to the numerous risk factors and tests applied will result in a limited power of the study. The results should therefore be interpreted carefully. The outcome of the analyses showed trends of the perception of the importance of risk factors of the different groups involved in the dairy sector. Causality between the relations found was not assumed. The sensitivity analysis showed that excluding participants with a regression coefficient smaller than 0.50 did not result in different outcomes. A cut-off value of the correlation coefficient of 0.30 seemed to be appropriate in this study.

A majority of the participants gave marks higher than neutral (i.e. 4; Table 4) for several questions in the evaluation. The ACA interview was perceived as realistic and interesting. Realism is often difficult to achieve in conjoint analysis, especially with a limited number of attributes (Horst et al., 1996a; Stärk et al., 1997). In this experiment, we included a large number of attributes (9) with many levels, in total 34. The more levels are included, the more realistic the interview, but also the more difficult and the longer. However, the evaluation showed that the ACA interview was not perceived as being too long or too difficult. For our objectives this ACA interview performed very well and we think that ACA will also be useful in interviews about introduction or spread of other infectious diseases with many possible risk factors.

The results of the multivariable logistic regression analysis of Van Schaik et al. (1998) showed that 'participation in cattle shows' and 'purchase of cattle' were direct animal contacts with odds ratios significantly larger than 1. Visitors (occasional and professional) were also significant risk factors and provision of protective clothing to visitors was a protective factor (Van Schaik et al., 1998). Comparing the results of the case-control study by Van Schaik et al. (1998) and Table 1 shows that the participants were well aware of the risk of direct animal contacts. However, the participants seemed to underestimate the risk from visitors. Therefore, people operating in the dairy sector might not be motivated to adopt or use protective clothing for visitors.

With the results of the ACA questionnaire it was possible to compare the perception of the importance of risk factors by farmers and their actual management practices. Farmers were aware of the risk represented by purchase of cattle or participation in cattle shows. Farmers who did purchase cattle or did participate in cattle shows thought the risks of direct animal contacts to be even higher than farmers who were not involved in these activities. For example, farms that purchase cattle thought the purchase of a bull for natural service even more risky than the non-purchasing farms (Table 3). Van Schaik et al. (1998) found that farms that were BHV1-positive more often participated in cattle shows. The results of the presented study show a trend that the BHV1-positive farms considered the risk of participation in cattle shows to be smaller than did BHV1-negative farms (Table 3). Van Schaik et al. (1998) found an odds ratio of 3.5 for participation in cattle shows, which suggested a high risk for introduction of BHV1. Extension should increase awareness of farmers of the risk of participation in cattle shows (without additional requirements with respect to diseases).

Although the farmers were aware of the risks they take with their actual management practices, they did not change their management accordingly. Advice to farmers should therefore focus on the practical implementation of the measures a farmer should adopt to minimize risk of introduction of infectious diseases. Furthermore, extension should not only focus on farmers, but also on other parties involved in the dairy sector such as veterinarians, AI technicians, cattle transporters and cattle traders. All stakeholders should be well aware of the risks they represent or accept taking. The necessary measures to decrease the risk of introduction of infectious diseases to dairy farms (a more closed farming system) require the support of all parties in the dairy sector. A more closed farming system can only be successful when all persons involved in the dairy sector make an effort to exclude or minimize risks.

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References

Conover, W.J., 1980. Practical non-parametric statistics. John Wiley and Sons, New York, 493 pp.

Green, P.E. and Srinivasan, V., 1990. Conjoint analysis in marketing: New developments with implications for research and practice. *Journal in Marketing*. Oct., 3-19.

Horst, H.S., Huirne, R.B.M. and Dijkhuizen, A.A., 1996a. Eliciting the relative importance of risk factors concerning contagious animal diseases using conjoint analysis: a preliminary survey report. *Preventive Veterinary Medicine* 27: 183-195.

Horst, H.S., Dijkhuizen, A.A., Huirne, R.B.M. and Steenkamp, J-B.E.M., 1996b. Eliciting expert opinions on risk factors concerning introduction of virus: application of conjoint analysis. In: Thrusfield, M.V. and Goodall, E.A., *Proceedings of the Society for Veterinary Epidemiology and Preventive Medicine*, Glasgow, 8-17.

Metegrano, M., 1994. Adaptive Conjoint Analysis - version 4.0, 1994. Sawtooth Software, Inc. Evanston, 311 pp.

Nagel, R., 1995. Basic figures on livestock demography and trading pattern in the Community. Animal health and related problems in densely populated livestock areas of the Community. In: Dijkhuizen, A.A. and Davies, G. (Eds), *Proceedings of a workshop of the European Commission*. Brussels, 7-31.

Nielen, M., Jalvingh, A.W., Horst, H.S., Dijkhuizen, A.A., Maurice, H., Schut, B.H., Van Wuijckhuise, L.A. and De Jong, M.F., 1996. Quantification of contacts between Dutch farms to assess the potential risk of foot-and-mouth disease spread. *Preventive Veterinary Medicine* 28; 3: 143-158.

Norusis, M.J., 1993. SPSS for Windows: base system user's guide, release 6.0. SPSS inc. Chicago, 828 pp.

Product Board for Livestock, Meat, and Eggs, 1997. Livestock, meat and eggs in the Netherlands. Rijswijk. 48 pp.

Stärk, K.D.C., Horst, H.S., Morris, R.S. and Teuffert, J., 1997. Elicitation of expert knowledge on risk factors for classical swine fever transmission in Switzerland. *Proceedings of the 8th International Symposium on Veterinary Epidemiology and Economics*. Paris: 12.24.1

Tazelaar, R.J. and Gerats, G.E., 1995. Industrial self-regulation to minimise the risk of animal disease and environmental pollution. Animal health and related problems in densely populated livestock areas of the Community. In: Dijkhuizen, A.A. and Davies, G. (Eds), *Proceedings of a workshop of the European Commission*. Brussels: 191-203.

Thomas, D.C., Siemiatycki, J., Dewar, R., Robins, J., Goldberg, M., and Armstrong, B.G., 1985. The problem of multiple inference in studies designed to generate hypotheses. *American Journal of Epidemiology* 122: 1080-1095.

Van Schaik, G., Dijkhuizen, A.A., Huirne, R.B.M., Schukken, Y.H., Nielen, M. and Hage, J.J., 1998. Risk factors for existence of Bovine Herpesvirus 1 antibodies on non-vaccinating Dutch dairy farms. *Preventive Veterinary Medicine* 34; 2,3: 125-136.

Van Wuijckhuise, L., Bosch, J., Franken, P., De Wit, J., Frankena, K. and Elbers, A., 1997. Some epidemiological characteristics of bovine Herpesvirus 1 (BHV1) infections as determined by bulk milk testing of all Dutch dairy herds. *Proceedings of the 8th International Symposium on Veterinary Epidemiology and Economics*. Paris: 11.13.1

Appendix

Perceptions of Dutch farmers, veterinarians and AI technicians (n=45) of risk factors for Bovine Herpesvirus type 1 transmission between dairy farms.

	Percentiles		
Risk factors	25th	50th	75th
Purchase of cattle			
No cattle purchased	0	0	0
Purchase of cattle at a sale or market place; tested by a veterinarian	12	29	49
Purchase of cattle at a sale or market place; cattle at least 14 d in quarantine	17	42	60
Purchase of cattle from a farmer; no precautionary measures	60	73	87
Purchase of cattle at a sale or market place; no precautionary measures	87	102	123
Preventive measures for visitors			
Protective clothing and boots provided by farmer for all visitors entering the barn	0	0	9
Protective clothing and boots provided by farmer for all visitors in direct contact with cattle	0	14	27
Disinfecting of footwear on entering the barn	11	32	42
Visitors who don't use protective clothing or boots	43	61	78
Contacts with material/machinery			
Manure applicators of hired mechanisators	0	11	27
Hosing machinery/tools down and prohibition of cattle trucks in the farm yard	0	20	39
Borrowed tools (e.g. cattle shaver, delivery materials)	9	25	38
Cattle trucks in the farm yard	11	30	45
Box for clipping claws of cattle	15	35	52
Use of natural service			
No natural service used	0	0	3
Bull is reared on own farm	0	19	34
Bull obtained from a cattle trader or farmer	72	84	101
Returning export cattle			
Rejected export cattle did not return to the farm	0	0	0
Rejected export cattle return to the farm	88	107	125
Participation in cattle shows			
No participation in cattle shows	0	0	0
Participation in cattle shows with a controlled disease status	11	25	34
Participation in cattle shows	50	67	87
Secondary farm business			
Beef cattle are stabled and/or grazing with dairy cattle	0	0	0
Sheep/goats are stabled and/or grazing with dairy cattle	0	0	0

Table continued

Risk factors	Percentiles		
	25th	50th	75th
Contacts with vermin			
Rats and mice	0	0	5
Flies	0	0	0
Birds	0	0	14
Dogs and cats	0	0	15
Cattle grazing near other cattle			
Cattle separated from other cattle by a distance of at least 50-m.	0	0	0
Cattle at least 3m separated by ditch or fence; no nose-to-nose contacts possible	10	23	35
Possible nose-to-nose contact with other cattle	68	84	113
Contacts through water and manure			
Ditch water used for drenching cattle	0	0	0
Chicken or pig manure is applied to fields one's cattle graze	0	0	0
Manure from other cattle farms is applied to fields one's cattle graze	0	0	23

Chapter 4

Risk factors for existence of Bovine Herpesvirus 1 antibodies on non-vaccinating Dutch dairy farms

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Abstract

A more closed farming system may prevent introduction of infectious diseases on dairy farms and can be a good starting point for control of these diseases. Data were available on the presence of Bovine Herpesvirus 1 (BHV1) antibodies in bulkmilk and/or bloodsamples of Dutch dairy farms. Furthermore, information about the possible risk factors for introduction of infectious diseases was collected on 214 of these dairy farms. Data of 107 farms that had never vaccinated against BHV1 remained for the analysis. A positive BHV1 status on these 107 farms could only be caused by introduction of BHV1. Risk factors for introduction of BHV1 on the farms were quantified using logistic regression. BHV1-positive farms purchased cattle and participated in cattle shows more often compared with BHV1-negative farms. A BHV1-positive farm also had more (professional) visitors in the barn who used farm clothing less often. The BHV1-positive farms were found to be situated closer to other cattle farms compared with the BHV1-negative farms.

4.1 Introduction

A major aim of the European Union (EU) livestock policy is to improve the health status of farm animals in the member states. Preventive measures to control health at the farm level are considered the major tool to realise this improvement. National borders are replaced by borders around the individual farm implying that individual farmers are responsible for the animal health status. Farmers need to be aware of the risks and management opportunities in order to maintain or improve the animal health status on the farm (Julicher et al., 1993).

Dutch agriculture is characterised by intensive animal production. In the past decades, the concentration of animals as well as the number of national and international contacts (i.e. trade of animals) have increased considerably (Nagel, 1995), putting strong pressure on a fixed health status (Tazelaar and Gerats, 1995). Other contacts (such as visitors or vehicles with animal contact) are also numerous on Dutch farms (Nielen et al., 1996). Those (animal) contacts can pose a serious threat to a fixed animal health status. Farmers should increase their awareness of the risk and costs of diseases, and change from curative health services to a more preventive veterinary approach.

This study explores the risk factors for introduction of Bovine Herpesvirus 1 (BHV1). Introduction of BHV1 was chosen because there was a good recording system of the BHV1 status of dairy farms. BHV1 causes the disease called Infectious Bovine Rhinotracheitis (IBR). During primary infection, BHV1 becomes latent in the ganglia of the central nervous system, where it persists for the life of the animal (Ackermann et al., 1990). BHV1 can be reactivated and may be shed and may induce primary infections in new susceptible animals.

BHV1 can spread easily within farms between cows (Ackermann et al., 1990; Hage et al., 1994; Wentink et al., 1993). The most common way of BHV1 transmission between farms is introduction of latently infected animals on a farm (Msolla et al., 1981; Pastoret et al., 1984). At first introduction, BHV1 causes severe clinical cases resulting in abortions and even deaths (Wiseman et al., 1980). A reintroduction only causes subclinical cases with minor effects on cow health (Verhoeff and Van Nieuwstadt, 1984). In 1998, a compulsory eradication program for BHV1 will be implemented in the Netherlands. The high prevalence of BHV1 in Dutch dairy cattle demands a special approach for eradication of the disease. An eradication program for BHV1 can only be successful when contacts between farms can be reduced or that these contacts can become less risky as to introduction of BHV1. According to the extension services (i.e. Animal Health Service and National Reference Centre for Livestock Production), a more closed farming system blocks the major routes of introduction (risk factors), which are (Koole, 1995) (any order):

- contact with other dairy cows (cows purchased, cows on cattle shows, et cetera);
- contact with other animal species that are potential carriers or vectors of the disease (sheep, rats, dogs, et cetera);
- transmission by humans (visitors, veterinarians, et cetera);
- transmission by machinery (cattle trucks, manure applicators, tools, et cetera);
- transmission by foodstuff or water (e.g. ditch water); and
- transmission by air (currents).

Most studies only mentioned a few possible risk factors for introduction of BHV1 but did not quantify these risk factors. The objective of this study was to explore and to quantify the risk factors for introduction of BHV1 on Dutch dairy farms by using logistic regression.

4.2 Materials and methods

4.2.1 Data collection

A case-control design was used. All case and control farms were non-randomly selected dairy herds with a known serological status for BHV1. The farms were selected from two databases. One database consisted of approximately 1800 Dutch dairy farms participating in a monthly bulkmilk examination for BHV1-status. The other database consisted of 172 farms that participated in trials of the Animal Health Service and where bloodsamples were taken from all milking cows twice a year. All farms were selected on the basis of their geographical position (namely, the northern provinces of the Netherlands). The cases were farms on which

1) all of the 9 monthly bulkmilk samples were antibody-titre positive, or 2) half-yearly bloodsamples showed that antigen-positive cows were present in the herd. Milk and bloodsamples were tested by undiluted gB-blocking. The controls were farms on which all bulkmilk samples or all bloodsamples were negative for antibodies against BHV1.

In January 1996, an introduction letter about the project was sent to 252 selected farms with a known BHV1 status. Then these farmers were called to ask whether they wanted to co-operate in the project. An appointment for an interview was made with the 214 farmers (85%, 131 cases and 83 controls) who were willing to co-operate. A questionnaire was formulated (based on advice from the extension services) to obtain information directly from the farmers. The questionnaire was divided into two parts. The first part consisted of questions a farmer could easily look up and fill in him(her)self, and was sent to the farmer before the personal interview. During the interview, the first part was completed if necessary and the second part of the questionnaire was filled out by the interviewer. Each question was read to the farmer and the appropriate answer category was selected based on the response. Data were collected about husbandry practices, disease status, personal characteristics, technical farm results and possible risk factors for introduction of infectious diseases on the farms. The questions asked were on 1995 and the 4 preceding years. The questionnaire was pre-tested on 6 dairy farms that were not included in the study. The farms to be visited were divided among 4 interviewers: the first author and 3 BSc students in Animal Science. The first 20 interviews were conducted in the same week and discussed together to prevent interviewer-bias as much as possible. The interviewers did not know anything about the BHV1 status of the farms. All farms were visited between February and April 1996 and 194 of 214 farms had complete data. The questionnaire resulted in about 600 variables. These 600 variables covered a broad range of information such as age, education and farm style of the farmers, preventive measures against farm specific diseases, milking practices, disease status for other infectious diseases (Leptospirosis, Paratuberculosis, Salmonella, BVD), et cetera. Supplementary (production) data were obtained from the Royal Dutch Cattle Syndicate (KNRS).

A preliminary study showed a considerable influence of the herd size on the 'closeness' of a farm (Van Schaik et al., 1997). De Jong et al. (1995) also found an association with herd size for other infectious diseases. Furthermore, the BHV1 status was highly influenced by vaccination (vaccinated cows keep a lifelong positive status for BHV1). Therefore, special attention was paid to the number of milking cows and vaccination against BHV1. 'Herd size' was tested thoroughly on being a confounder by calculating correlations and interaction terms. For the analysis, a subgroup of 107 farms that said to have never vaccinated against BHV1 was used. A positive BHV1 status of these farms could only be caused by introduction of BHV1 or by cattle with vaccine antibodies. The subgroup consisted of 45 cases and 62 controls.

4.2.2 Data analysis

Selection of variables for the multivariable analysis was carried out in two ways. First, all risk factors based on the major routes of introduction advised by the extension services were selected for the multivariable analysis. Second, other variables were screened by using a subset approach recommended by Hosmer and Lemeshow (1989) for situations in which the total number of possible predictor variables greatly exceeds the degrees of freedom allowed in the model, as was the case in this study. For this approach a univariable analysis was carried out on BHV1 status of the farm. Independent-sample T-test and Mann-Whitney Test were used for continuous variables and χ^2-analysis was used for categorical variables to test whether or not a variable was associated with the BHV1 status by a liberal *P*-value of 0.25 (Hosmer and Lemeshow, 1989). Some variables were tested as continuous as well as dichotomous variables. Categorical variables with more than two categories were transformed into two or more dummy variables and compared by χ^2-analysis on BHV1 status. This was done to determine whether distinction among the categories was important. Based on these results two or more categories could be combined with minimal loss in predictive ability and the final categorical variables only consisted of two categories. The results of the univariable analysis were used in further multivariable analysis.

In the second part of the analysis logistic regression was used to analyse the multivariate relationships between risk factors and BHV1 status, including interaction terms (Hosmer and Lemeshow, 1989). The statistical analysis was carried out by using the LOGISTIC REGRESSION procedure in SPSS 6.1 (SPSS Advanced Statistics 6.1, 1994). Odds ratios from the univariable analysis (Table 1) were compared with those from the multivariable analysis. If those odds ratios differ considerably the variable might be a confounder or interaction term. Collinearity between the variables was investigated by means of the bivariate correlation coefficients. None of the variables had a correlation coefficient larger than 0.50. No confounders were found and possible interaction terms were tested for significance. In the "starting" multivariable model, all remaining risk factors (approximately 20) were offered initially. When interaction occurred the odds ratios and Confidence Interval (CI) were calculated according to the method of Hosmer and Lemeshow (1989). The risk factors initially offered to the model were excluded from the model with a conditional backward elimination procedure, then the possible interaction terms were investigated with a forward conditional selection procedure in SPSS 6.1. A factor was entered in the model at $P \leq 0.05$ and removed at $P \geq 0.10$.

The attributable proportion (AP) and prevented fraction (PF) were calculated as:

$$\mathrm{AP} = \frac{\mathrm{OR}-1}{\mathrm{OR}} * f \text{ (for OR > 1), and} \tag{1}$$

$$\mathrm{PF} = 1 - \mathrm{OR} \text{ (for OR < 1)} \tag{2}$$

in which f is the proportion of cases that is exposed to the risk factor. The AP and PF of the continuous exposure variables were calculated by comparing farms with a low exposure (those with no exposure or when this group was smaller than 10% of the farms, those with the lowest decile) with the mean of the exposure of the rest of the farms (Schukken et al., 1990). The PF of an interaction term was calculated in the way Rothman (1986) described.

Table 1: Summary of categorical variables offered to the multivariable analysis of BHV1 status.

Variable	Description	Cases (n=45)	Controls (n=62)
Sharing pasture[a]	Cattle are grazed on other farms (1)	12	7
	Not practised (0)	33	55
Occasional visitors[a]	At least once a week an occasional visitor (e.g. neighbours, family, friends) in the barn (1)	21	14
	Less than once a week (0)	24	48
Temporary workers[a]	A temporary worker who comes in contact with cows from other farms (1)	12	6
	No temporary worker on the farm or worker does not come in contact with cows from other farms (0)	31	56
Cattle shows[a]	Cows to cattle shows at least once during the preceding five years (1)	14	12
	No participation during the preceding five years (0)	31	50
Returning export cattle[a]	Cattle sold for export returns from the export stables (1)	14	10
	Export cattle never returns on the farm (0)	31	52
Embryo transplantation	Embryo transplantation carried out on the farm (1)	4	3
	No embryo transplantation in 1990-1995 (0)	41	59
Nose-to-nose contacts[a]	Nose-to-nose contacts are possible with grazing cattle from other farms (1)	8	17
	No such contacts possible (0)	37	45
Machinery	Machinery or tools from other farms are used (1)	5	8
	No machinery or tools from other farms are used (0)	40	54
Use of AI only[a]	Only Artificial Insemination used to breed the cows (1)	20	36
	Also a bull used to breed the cows (0)	25	26
Cattle breach or escape	Cattle breach or escape from their confined areas and mingle with other herds (1)	17	24
	Cattle never breach or escape from their confined areas (e.g. pasture) and mingle with other herds (0)	28	38
Presence of farm clothing and/or boots	Visitors (e.g. veterinarians) have to wear farm clothing or disinfect their boots when entering the stable (1)	9	13
	Visitors do not take precautionary measures when entering the farm (0)	36	49

[a] $P \leq 0.25$ in univariable analysis

Table 2: Summary of continuous variables offered to the multivariable analysis of BHV1 status, differences in medians per group tested by independent-sample Mann-Whitney Test (P≤0.25)

Variable	Description	Cases (n=45)			Controls (n=62)		
		Median	10th perc.	90th perc.	Median	10th perc.	90th perc.
Herd size[a]	Average number of milking cows between August 1994 and August 1995	56.0	33.0	82.8	48.0	23.0	75.1
Distance to nearest farm (in 100 m)[a]	The distance in 100 metres to a neighbouring dairy or cattle farm	2.5	0.5	5.0	3.0	1.2	8.0
# of cattle purchased[a]	Number of cattle purchased between June 25 1994 and September 25 1995	4.0	0.0	19.8	1.0	0.0	7.1
# visits AI technician[a]	The number of visits by an AI technician per year according to the farmer	104.0	0.0	163.6	100.0	1.5	150.0
# visits veterinarian[a]	The number of visits by a veterinarian per year according to the farmer	24.0	12.0	52.0	24.0	8.6	51.4
# youngstock sharing pasture[a]	Number of youngstock sharing pasture on other farms or with other cattle on one's own farm	0.0	0.0	20.4	0.0	0.0	0.0
# cows sharing pasture[a]	Number of cows sharing pasture on other farms or with other cattle on one's own farm	0.0	0.0	1.4	0.0	0.0	0.0
# youngstock to cattle shows[a]	The number of youngstock (calves) which participated in cattle shows	0.0	0.0	2.4	0.0	0.0	2.0
# cows to cattle shows	The number of milking cows which participated in cattle shows	0.0	0.0	1.0	0.0	0.0	1.0

[a] *P*≤0.25 in univariable analysis

4.3 Results

4.3.1 Results of the univariable analysis

Sixty-two farms were free of BHV1 and 45 farms were BHV1-positive. Tables 1 and 2 describe some categorical and continuous risk factors included in the univariable analysis.

4.3.2 Multivariable logistic regression

The final model (Table 3) correctly classified 76% of the farms for BHV1. The calculation of the AP was somewhat cumbersome for continuous variables. An example of the calculation of the AP of 'number of cattle purchased' may clarify the procedure used. Non-purchasing farms were compared with the average number of cattle purchased on the purchasing farms. Thirty-four farms did not purchase, 10 cases and 24 controls. Seventy-three farms did purchase on average 6.6 cows, i.e., 35 cases and 38 controls. The odds ratio of purchasing was 2.2 and the f was 0.56 (the number of cases which did purchase (n=35) divided by the total number of cases (n=62)). The calculated AP was 0.31.

Table 3: Multivariable logistic regression model of risk factors associated with positive BHV1 antibody status in unvaccinated dairy farms (n=107, -2loglikelihood=91.5, $\chi^2 = 0.54$)

Variable	β	SE(β)	*P*	OR	95% CI	AP or PF
At least once a week an occasional visitor (e.g. neighbours, family, friends) in the barn	1.40	0.59	0.02	4.06	1.28-12.9	0.35
Temporary workers	1.18	0.68	0.08	3.27	0.86-12.3	0.19
Participation in cattle shows	1.26	0.65	0.05	3.54	0.99-12.6	0.22
Presence of farm clothing and/or boots	1.91	1.13	0.09	6.73[a]	0.74-61.9	
Distance to nearest cattle farm (100 m)	-0.36	0.12	0.00	0.70	0.55-0.88	0.74[b]
Number of cattle purchased in 1995	0.28	0.07	0.00	1.32	1.15-1.52	0.31[c]
# of visits of AI technicians (10 visits)	0.04	0.05	0.43	1.04[d]	0.94-1.15	
Interaction: AI technician*farm clothing	-0.03	0.01	0.02	0.97	0.95-0.99	0.03[e]

[a] The OR was calculated for the situation that no AI technicians visited the farm. The OR was not significant.

[b] The PF was calculated by comparing a distance of less than 100 m with on average 400 m.

[c] The AP was calculated by comparing no cattle purchased with on average 6.6 cattle purchased per year.

[d] The OR was calculated for the situation that no farm clothing was present. The OR was not significant.

[e] The combined PF of the main effects and the interaction effect was calculated.

Herd size was not significant. Farms that had never vaccinated against BHV1 and had a positive BHV1 status were closer to other cattle farms, participated in cattle shows more often, had a temporary worker who also worked on other farms more often, purchased more cattle, and had more occasional visitors in the barn. The interaction term between 'AI technician' and 'presence of farm clothing' means that when AI technicians (or other visitors) used farm clothing and/or boots, a farm was less likely to be BHV1-positive compared with a farm where no farm clothing was used. The AP of the interaction term of 0.03 was very low. The AP or PF of the other variables in the model were of a considerable size (0.17 to 0.74).

4.4 Discussion and conclusions

4.4.1 Risk factors

Extension services and literature assume that the most important risk factors for introduction of BHV1 are direct and lengthy contacts between unfamiliar cattle (such as cattle purchased, cattle shows, cattle brought together in export stables) (Msolla et al., 1981; Pastoret et al., 1984; Wentink et al., 1993). Msolla et al. (1981) found that 'self-contained herds' (dairy or beef suckler herds into which no female cattle were said to have been introduced for several years) were BHV1-positive 2.8 times less often compared with herds in which female cattle had been introduced recently. The results of our analyses (Table 3) confirmed 'purchase of cattle' as a risk factor. We found that the odds ratio for the purchase of one cow was 1.32, which was a smaller figure than found by Msolla et al. (1981), but their figure is most likely based on the purchase of more than one cow. The farms in this study on average had purchased 4.5 cows per year, which would result in an odds ratio of 3.5. None of the other risk factors found in our study were quantified in the literature. Not only direct animal contacts are important but also workers and visitors on the farm and the infection pressure from other farms in the neighbourhood.

To prevent collinearity not all professional visitor groups (e.g. veterinarians, AI technicians) could be included in our model at the same time. Our model included the number of visits of AI technicians. However, these visitors could be replaced with any other professional visitor group such as veterinarians or cattle traders. Replacing the visits of AI technicians in the multivariable model with a different professional visitor group (e.g. veterinarians) hardly changed the odds ratios of 'the number of visits' and the odds ratios of the other risk factors in the model. AI technicians as well as veterinarians and cattle traders visited large farms more often than small farms; the number of professional visits is an indirect measure of herd size. 'Farm clothing' was an effect modifier for the association between 'the number of visits of AI technicians' and BHV1 status. The use of farm clothing decreased this association. However, this effect was based on only a few farms that used farm clothing, the PF of the factor was low and our faith in effect is small until it is confirmed by others.

The 'distance to the nearest cattle farm' was a fixed factor for the farmer. The risk related to this factor might consist of several factors, such as air currents, visits of the neighbour farmers or children, contacts between cattle of neighbouring farms, and contacts by other animals (cats, dogs, mice, rats et cetera) of neighbouring farms. The different factors within 'distance' could not be distinguished. When 'distance' was checked for collinearity no significant correlation with other factors were found. The size of the PF (0.74) of 'distance' emphasised the importance of this risk factor and the need for further research.

4.4.2 Non-significant risk factors

'Participation in cattle shows' (as a binary variable) was offered to the model based on a priori decisions. The distribution of the continuous variable 'number of cows participating in cattle shows' was strongly skewed because most of the farmers never went to cattle shows (75.7%) and had a zero value, and only 24.3% went to cattle shows with one or more cows per year. Within the group of farmers who participated in cattle shows, a secondary model was run including the number of cows participating; there was no linear relationship between the number of cows participating in cattle shows and BHV1 status. 'Sharing pasture' was significantly different between BHV1-positive and BHV1-negative farms in the univariable analysis, but not in the multivariable model (Deviance=0.17, df=1, P=0.68). The continuous variable 'the number of youngstock shared on or of other farms' was tested in the same way as 'the number of cows participating in cattle shows'. Within the group of farms that shared youngstock no linear relation between the number of youngstock shared and BHV1 status could be found. This result was also based on a few farms (n=18). Other risk factors expected to be important for introduction of BHV1 were not found significant in the final multivariable model. 'Returning export cattle', 'use of AI only', 'nose-to-nose contacts', 'borrowing machinery', and 'cattle breach or escape' were found non-significant in the multivariable analysis.

4.4.3 Herd size

Msolla et al. (1981) found a tendency that larger herds were BHV1- positive more often. It is possible that reservoir maintenance and exposure potential may provide more susceptible contacts for an infectious disease in larger herds than they do in smaller herds (De Jong et al., 1995). Larger herds not necessarily have more outside contacts (e.g. cattle purchased, visits of veterinarians, et cetera) per cow but do have more contacts in total and each contact may imply an introduction of BHV1. The association between herd size and BHV1 status also could be attributable to confounding with other risk factors associated with herd size (Enevoldsen et al., 1996). In our study, 'herd size' was strongly correlated with some other risk factors. The number of visits of professional visitors, such as veterinarians and AI technicians was mainly dependent on the number of cows on a farm. 'Herd size' thus becomes a cluster variable for several risk factors (professional visitors, number of cows purchased, temporary and regular workers, et cetera). However, the goal of our study was to find critical risk factors for introduction of BHV1, which the farmer can influence. 'Herd size' is not manageable by the farmer in this respect. In the multivariable analysis 'herd size' was offered to the model but not included in the final model (Table 3) by the backward elimination procedure. This supported the hypothesis of 'herd size' not being a confounder, but an indirect effect.

4.4.4 Bias

A non-vaccinated subgroup of farms was selected to better evaluate the associations between risk factors for introduction of BHV1. These farms might be run by farmers with a less risky management related to introduction of diseases and who therefore saw no need to vaccinate. This was supported by the data. The presence of several risk factors was significantly lower in the non-vaccinating subgroup compared with the vaccinated group that was excluded from the analysis (data not shown). Farms in the non-vaccinating subgroup less often participated in cattle shows, shared cattle, or had the possibility of nose-to-nose contacts of cattle. Furthermore, the farms had a smaller herd size, purchased fewer cows and the veterinarian and AI technician visited the farm less often. However, the data also showed that non-vaccinating farmers who purchased cattle did not take more preventive measures (e.g. quarantine, testing of the cattle) than vaccinating farmers. Therefore we belief that, the association of the risk factors with BHV1 status would probably not differ between non-vaccinating and vaccinating farms.

The farms for the study were selected non-randomly. All farms were situated in the northern provinces of the Netherlands. Farm management might differ between different parts of the Netherlands. We think that the causal relation between a risk factor and the disease status of a farm will not differ between farms. However, the prevalence of BHV1 in the northern region of the Netherlands (75%) is slightly lower than in the eastern (79%) and southern regions (84%) and higher than in the west and middle regions (57%) (Van Wuijckhuise et al., 1993). The infection pressure of BHV1 will differ between farms situated in the northern region or elsewhere in the Netherlands. Therefore, caution is necessary when generalising the data for the Netherlands or other countries with a different number of farms per km^2 and/or BHV1 prevalence.

Part of the farms were selected from 1800 farms that participated in a monthly bulkmilk sampling regime for BHV1 of the Animal Health Service. Other farms were selected from trials in which bloodsamples were taken from all milking cows twice yearly for BHV1. The farms in our study had a slightly lower prevalence of BHV1 (66% BHV1-positive) compared with the overall prevalence in the Netherlands (75%)(Van Wuijckhuise et al., 1993). Farms that participated in trials of the Animal Health Service and in our study might be more aware of the risk of introduction of BHV1. They might take measures against introduction of BHV1, which they had not done a few years ago when BHV1 possibly was introduced on the farms. In the questionnaire questions were asked on present management and that of the four preceding years. Because respondents tend to be less accurate about the past, the answers about the management in the past will be more like the present management. Therefore, the associations between risk factors for introduction of BHV1 (which depend on management) and the BHV1 status might be biased. The present BHV1 status might be a result of the management in the past that a farmer did not recall accurately. Furthermore, some of the BHV1-negative farms might already have known their BHV1-free status. Those farmers were more aware of the risk of introduction of BHV1 and more able to recall the possible risk factors. This recall bias (differential misclassification) would result in underestimation of the associations between risk factors and BHV1 status (Rothman, 1986), the odds ratios go 'toward the one'.

On eleven farms that were negative in their bulkmilk samples, bloodsamples were also taken. Two (18%) of these 11 farms turned out to have 3 of 65 cows and 1 of 35 cows positive for BHV1 respectively. We therefore extrapolate that of the 60 farms with a negative BHV1 status according to their bulkmilk samples, 10 (18% of 60) farms may have had a few BHV1-positive cows. Misclassification of truly BHV1-positive herds is not expected because the specificity of nine subsequent bulkmilk tests and two yearly blood tests is very high. Therefore, 9% of the farms (10 farms of 107 farms) might have been misclassified as a BHV1-negative farm. This nondifferential misclassification will lead to an underestimation of the odds ratios of the risk factors, the odds ratios go 'toward the null' (Rothman, 1986).

4.4.5 Concluding remarks

This paper dealt with an exploratory study of the influence of factors that might be associated with a positive BHV1 status of a farm. The purpose was to evaluate advice of the extension services and identify and quantify factors that could be further examined in other ways or that might be amenable to manipulation by farmers.

Purchase of cattle and participation in cattle shows were respectively 1.3 and 3.5 times more likely on farms with a positive BHV1 status and the AP of both risk factors was 0.31 and 0.22 respectively. The farmer should prevent direct and lengthy animal contacts in order to reduce the risk of introduction of BHV1 considerably. However, the study also showed that a farmer should focus on workers and visitors (occasional and professional) and the use of farm clothing and boots by these visitors. At least once a week occasional visitors in the barn, a temporary worker who also worked on other farms was respectively 4.0 and 3.3 times more likely on BHV1-positive farms and an interaction term between 'number of visits of AI technicians' and 'presence of farm clothing' had an odds ratio of 0.97. The 'distance to the nearest cattle farm' was a preventive factor (OR=0.7) with a high PF of 0.74. This variable possibly included other neighbourhood contacts and infection pressure from neighbouring farms. Successful prevention of introduction of BHV1 on a farm might therefore be dependent on the BHV1-status and preventive measures taken on neighbouring cattle farms.

Final decisions about implementations of management measures to reduce the chance of introducing BHV1 on the farm must eventually be made on the basis of economic comparisons of the expected benefits of a more closed farming system with the costs of implementing those measures (e.g. rearing own youngstock, providing farm clothing).

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References

Ackermann, M., Müller, H.K., Bruckner, L. and Kihm, L., 1990. Eradication of infectious bovine rhinotracheitis in Switzerland: review and prospects. *Veterinary Microbiology* 23: 365-370.

De Jong, M.C.M., Diekmann, O. and Heesterbeek, J.A.P., 1995. How does transmission depend on population size? In: Mollison, D. (Ed), Epidemic models: Their structure and relation to data. Cambridge University Press, Cambridge, pp 84-94.

Enevoldsen, C., Hindhede, J. and Kristensen, T., 1996. Dairy herd management types assessed from indicators of health, reproduction, replacement, and milk production. *Journal of Dairy Science* 79: 1221-1236.

Hage, J.J., Schukken, Y.H., Barkema, H.W., Benedictus, G. and Wentink, G.H., 1994. Population dynamics of BHV1 infection in a dairy herd. In: Schukken, Y.H. and Lam, T.J.G.M. (Eds), *Proceedings of the 7th meeting of the Dutch Society for Veterinary Epidemiology and Economics*. Utrecht, pp. 41-54.

Hosmer, D.W., and Lemeshow, S. (Eds), 1989. Applied logistic regression. John Wiley and Sons, Inc., New York, 307 pp.

Julicher, C.H.M., Van Klink, E.G.M., De Peuter, G., Schumer, D.L. and Versteijlen, G.H.J.M., 1993. De toekomst van de diergezondheid. Final report. The Hague, 62 pp. (in Dutch)

Koole, H., 1995. Hygiene melkveebedrijven. IKC publication. Lelystad, 15 pp. (in Dutch)

Msolla, P.M., Wiseman, A. and Selman, I.E., 1981. The prevalence of serum neutralized antibodies to infectious bovine rhinotracheitis virus in Scotland. *Journal of Hygiene* 86: 209-215.

Nagel, R., 1995. Basic figures on livestock demography and trading pattern in the Community. Animal health and related problems in densely populated livestock areas of the Community. In: Dijkhuizen, A.A. and Davies, G. (Eds), *Proceedings of a workshop of the European Commission*. Brussels, 7-31.

Nielen, M., Jalvingh, A.W., Horst, H.S., Dijkhuizen, A.A., Maurice, H., Schut, B.H., Van Wuijckhuise, L.A. and De Jong, M.F., 1996. Quantification of contacts between Dutch farms to assess the potential risk of foot-and-mouth disease spread. *Preventive Veterinary Medicine* 28, 3: 143-158.

Pastoret, P.-P., Thiry, E., Brochier, B., Derboven, G. and Vindevogel, H., 1984. The role of latency in the epizootiology of infectious bovine rhinotracheitis. In: Wittmann, G., Gaskell, R. and Rziha, H.-J. (Eds), Latent Herpesvirus Infections in Veterinary Medicine. Martinus Nijhoff Publishers, The Hague, 211-228.

Rothman, K.J., 1986. Modern epidemiology. Little, Brown and Company, Boston, 358 pp

Schukken, Y.H., Grommers, F.J., Van de Geer, D., Erb, H.N. and Brand, A., 1990. Risk factors for clinical mastitis in herds with a low bulkmilk somatic cell count. 1. Data and risk factors for all cases. *Journal of Dairy Science* 73: 3463 - 3471.

SPSS Advanced Statistics 6.1. SPSS Inc., Chigago, Illinois, 1994, 606 pp.

Tazelaar, R.J. and Gerats, G.E., 1995. Industrial self-regulation to minimise the risk of animal disease and environmental pollution. Animal health and related problems in densely populated livestock areas of the Community. In: Dijkhuizen, A.A. and Davies, G. (Eds), *Proceedings of a workshop of the European Commission*. Brussels, 191-203.

Van Schaik, G., Dijkhuizen, A.A., Huirne, R.B.M., Benedictus, G., Barkema, H.W. and Koole, J.L., 1997. An exploratory study on the economic value of a more closed farming system on Dutch dairy farms. *The Veterinary Record*, March 7 (1998) 240-242.

Van Wuijckhuise, L., Bosch, J., Franken, P., Hage, J.J., Verhoeff, J. and Zimmer, G., 1993. The prevalence of infectious Bovine Rhinotracheitis (IBR) in the Netherlands. In: Elbers, A.R.W. (Ed), *Proceedings of the 6th meeting of the Dutch Society for veterinary epidemiology and economics*. Boxtel, pp. 7-16.

Verhoeff, J. and Van Nieuwstadt, A.P.K.M.I., 1984. BRS virus, PI3 virus and BHV1 infections of youngstock on self-contained dairy: Epidemiological and clinical findings. *The Veterinary Record* 114: 288-293.

Wentink, G.H., Van Oirschot, J.T. and Verhoeff, J., 1993. Risk of infection with bovine Herpesvirus 1 (BHV1): a review. *Veterinary Quarterly* 15: 30-33.

Wiseman, A., Msolla, P.M., Selman, I.E., Allan, E.M. and Pirie, H.M., 1980. Clinical and epidemiological features of 15 incidents of severe infectious bovine rhinotracheitis. *The Veterinary Record* 107: 436-441.

Chapter 5

Application of survival analysis to identify management factors related to the rate of BHV1 seroconversions at Dutch dairy farms.

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Abstract

The prevalence of BHV1 at dairy farms is dependent on several factors. First, the prevalence is influenced by introduction of BHV1 at the farms, which is dependent on the risk factors for introduction. Second, the BHV1 prevalence might also be influenced by reactivation of BHV1 within the farm, which might be affected by the management of the farmer. In this study the relations between risk factors, management factors and the estimated time since latest BHV1 outbreak were investigated by means of Cox regression analysis. The results showed that direct animal contacts (i.e. purchase of cattle and returning export cattle) and occasional visitors increased the rate of BHV1 outbreaks on dairy farms. Management factors related to reactivation of BHV1 at dairy farms were all related to a loose housing system, which incurred an increased risk of reactivation of BHV1 at the farm. The reactivation was facilitated when the barn was overcrowded (i.e. more cows than cubicles in the barn).

To minimize the risk of introduction of BHV1 at a farm the farmer should banish direct animal contacts and limit the number of contacts with visitors. Stress and an overcrowded barn should be avoided.

5.1 Introduction

Bovine herpesvirus type 1 (BHV1) causes the disease called Infectious Bovine Rhinotracheitis (IBR). During primary infection, BHV1 becomes latent in the ganglia of the central nervous system, where it persists for the life of the animal (Ackermann et al., 1990a). BHV1 can be reactivated and shed and may induce primary infections in susceptible animals. BHV1 can spread easily within farms between cows (Ackermann et al., 1990a; Hage, 1997; Wentink et al., 1993). The most common way of BHV1 transmission between farms is introduction of latently infected animals (Msolla et al., 1981; Pastoret et al., 1984). At first introduction, BHV1 may cause severe clinical cases resulting in abortions and even mortality (Wiseman et al., 1980). A re-introduction usually leads to subclinical cases with minor effects on cow health (Verhoeff and Van Nieuwstadt, 1984). In 1998 a compulsory eradication program for BHV1 was implemented in the Netherlands. The high prevalence of BHV1 in Dutch dairy cattle requires a special approach for eradication of the virus. Although a marker vaccine for BHV1 is used in the eradication program, the program can only be successful when spread between farms can be reduced (Bosch, 1997a).

Dutch dairy farms differ considerably in management as to potential introduction of infectious diseases. A study was carried out by Van Schaik et al. (1998) to quantify risk factors for prevalence of BHV1 at dairy farms. The study revealed that purchase of cattle, participation in cattle shows, and professional and occasional visitors were present on BHV1 antibody positive farms more often. The use of protective clothing and boots by professional visitors and the distance to other cattle farms were preventive factors for the presence of BHV1 at a farm. Prevalence of BHV1 at Dutch dairy farms differs considerably and is generally high (Van Wuijckhuise et al., 1993). This may partly be caused by introduction of BHV1 into farms, but also be influenced by reactivation of the virus at the farm (prevalence = incidence * duration). Under field conditions it is often difficult to distinguish between virus introduction or reactivation of latent virus. Only when negative herds are studied longitudinally it is possible to evaluate factors specifically related to virus introduction.

Transmission of BHV1 within a farm would mostly be prevented by limiting contacts between BHV1-negative and BHV1-positive animals (Ackermann et al., 1990b). Eradication of BHV1 at a Swiss beef farm was possible by changing the management to prevent transmission of the virus (Ackermann et al., 1990b). Cows only reexcrete virus either under natural stressed conditions or, artificially, with a high dose of dexamethasone (Hage, 1997). The relationships between management, reactivation and transmission of BHV1 are still unclear.

It is assumed that 85% of the BHV1 outbreaks in a fully susceptible population will be major and lead to complete spread. In a herd with many seropositive animals the chance of a major outbreak decreases. In a herd with e.g. 40% seropositive animals, only 70% of the outbreaks will be major and cause all seronegative animals to seroconvert (Bosch et al., 1998; Hage et al., 1998). The prevalence of BHV1 in youngstock after an outbreak is often independent from the prevalence in the milking herd. The prevalence in youngstock tends to be lower (Van Wuijckhuise et al.,1993; Bosch et al., 1998). Therefore, most heifers introduced in the milking herd are BHV1-negative. The seronegative animals in the milking herd can then be infected by introduction of the virus from outside the farm or by reactivation of seropositive animals. Introduction or reactivation of BHV1 at Dutch dairy farms is a relatively rare event and occurs approximately once in 3.5 years (Hage et al., 1998; Nieuwstadt and Verhoeff, 1983; Vonk Noordegraaf et al., 1998).

The Cox regression model (Cox, 1972) is a very flexible tool when analysing the effect of several factors on the time to an event, e.g. time to infection with a disease (Thomsen et al., 1992). In the present paper we apply the Cox regression model in an analysis of the relationship between management factors and the seroconversion rate of BHV1 at Dutch dairy farms (the survival time). The underlying process is that in a certain time period every farm has a (small) chance of introduction or reactivation of BHV1. The results should reveal which management practices are related to the rate of introduction and/or reactivation of BHV1 at the farm.

5.2 Materials and Methods

5.2.1 Data collection

Farm data were obtained from three sources, i.e. the Animal Health Service, the Dutch Cattle Syndicate (NRS) and a questionnaire (Van Schaik et al., 1998). The questionnaire was described in detail by Van Schaik et al. (1998) and was used (spring 1996) to collect management data of the past five years of 214 Dutch dairy farms. The farms under investigation were non-randomly selected dairy herds with a known serological status for BHV1 in 1995. The BHV1 status was known by 1) nine monthly bulk milk samples (131 farms), or 2) half yearly blood samples (83 farms) of the cows showing whether or not antibody positive cows were present in the herd. Milk and blood samples were obtained in 1995 and tested by undiluted gB-blocking ELISA (Kramps et al., 1994). The BHV1 prevalence was highly influenced by vaccination; vaccinated cows keep a lifelong positive status for BHV1 antibodies. Therefore, all farms, which were known to have vaccinated against BHV1 in the period from 1992 to 1997 were excluded from this analysis and 107 farms, 45 of which BHV1-positive and 62 BHV1-negative, remained.

On 50 of the 107 non-vaccinating farms blood samples of all cattle from the age of about one year old were collected on an individual-cow basis and tested for BHV1 antibodies by undiluted gB-blocking ELISA by the Animal Health Service. Furthermore, a list of all cattle present on these farms in December 1995 was obtained from the Dutch Cattle Syndicate. On 33 farms all dairy cows were BHV1-negative. The time since the latest seroconversion for BHV1 was therefore assumed to be at least as long ago as the age of the oldest cow on the farm. The time to event in days of these censored cases was the test-date minus the age of the oldest cow. On 17 farms one or more BHV1-positive cows were found. On these farms the latest seroconversion was assumed to have occurred as many years ago as the age of the youngest seropositive cow. The time to event on the BHV1-positive farms (the events) was calculated as the test-date minus the age of the youngest BHV1-positive cow.

5.2.2 Data analysis

The data (see appendix) were analysed by using Cox regression analysis, a proportional hazards analysis. The analysis was carried out using the COX REGRESSION procedure in SPSS 6.1 (Norusis, 1994). The proportional hazards model assumes that the log of the hazard rate (HR) can be modelled as a linear function of explanatory variables (Kleinbaum, 1996). The HR represents the rate of BHV1 outbreaks (either related to reactivations or to introduction) and is related to "time since latest BHV1 outbreak". The continuous variables were checked as to normality and linearity. If necessary, variables were normalized and non-linear variables were categorized.

The proportional hazards model assumes that the ratio of the hazards of two cases will be constant for all points in time (Kleinbaum, 1996). The proportionality assumption was evaluated individually for each explanatory variable by including a time-dependent covariate in the model representing the interaction of the explanatory variable with the time since latest seroconversion. If this term was significant (Wald's χ^2, $P \leq 0.10$), then the assumption that the HR for the variable was constant over time was considered inadequate and the time-dependent covariate was included in the final model (Kleinbaum, 1996).

All management variables expected to be important for introduction and reactivation of BHV1 at the farm were tested in univariable Cox regression analysis. Variables that were associated ($P \leq 0.25$) with the dependent variable (rate of BHV1 outbreaks) were included in a full model. Correlation between variables was checked with bivariate two-tailed correlation coefficients. When two variables had a correlation coefficient greater than 0.50, the one with the weakest relationship with the dependent variable was excluded from the full model. Three full multivariable models were built; the first model contained risk factors assumed to be related to introduction of BHV1 at a farm, the second model contained management factors assumed to be related to reactivation of BHV1 at the farm, and the third model contained both of these risk and management factors. The final models were obtained by a backward conditional elimination procedure ($PIN \leq 0.05$, $POUT \geq 0.10$). All two-way interaction terms were tested for significance at $P \leq 0.10$. Hazard rates were calculated as e^{β} and 90% confidence intervals (90%CI) as $e^{\beta \pm (1.65)(SE(\beta))}$ where β is the parameter estimate in the proportional hazards model.

A sensitivity analysis was carried out to check the influence of extreme cases. Extreme cases were defined as cases with the 5% highest and 5% lowest '# of days since latest BHV1-seroconversion'. These were cases with a time since latest BHV1 seroconversion smaller than 365 days and higher than 5110 days. The lower limit will exclude farms on which cattle younger than one year old were sampled and that might still have maternal antibodies to BHV1. The upper limit will exclude farms with cows that were older than 14 years.

5.3 Results

5.3.1 Survival analysis

The continuous variables were investigated and all were linear functions of the log of the HR. None of the time-dependent covariates was significant in the final models. All variables tested in the univariable analyses are shown in the Appendix. Figure 1 shows a histogram of the number of years since the last BHV1 seroconversion of the 50 farms, 17 farms experienced a seroconversion for BHV1; 33 farms were censored.

Of the 50 farms 17 farms (34%) had one or more cows with antibodies to BHV1. The time since the youngest cows on these farms seroconverted ranged from 98 days till 5169 days.

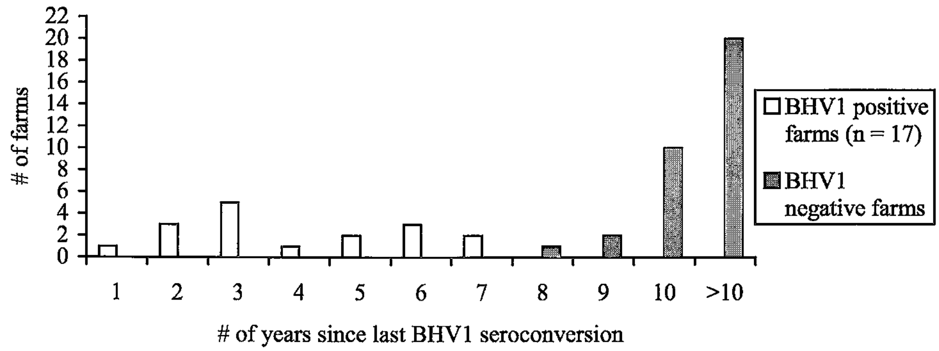

Figure 1. Histogram of the number of years since the last BHV1 seroconversion at 50 farms.

5.3.1.1 Survival analysis of risk factors related to introduction

In the univariable Cox regression six risk factors related to possible introduction of BHV1 at the farm were related to the 'rate of outbreak of BHV1' with $P \leq 0.25$. These variables were '# of cows which went to cattle shows', '# of cattle purchased in 1995', 'rejected export cattle returned on the farm', 'occasional visitors', 'a temporary worker who also works on other farms', and '# of professional visitors on the farm'. The variables '# of cows that went to cattle shows' and 'rejected export cattle returned on the farm' were highly correlated ($r = 0.60$, $P = 0.00$)., 'Rejected export cattle returned on the farm' was stronger related to the 'rate of BHV1 outbreaks' and was therefore included in the multivariable Cox regression. All other variables were not ($R \leq 0.50$) correlated. The multivariable analysis of the risk factors resulted in the final model shown in Table 1. The interaction term of 'rejected export cattle returned on the farm' and 'occasional visitors' was significant ($P = 0.04$). The interaction was not included in the final model, since none of the BHV1-negative farms had export cattle returned, nor many occasional visitors.

The multivariable Cox regression analysis resulted in four risk factors for introduction of BHV1, which were related to the 'rate of BHV1 outbreaks'. The HR of 1.13 showed that one cow purchased increased the 'rate of BHV1 outbreaks' by 1.13. The 'rate of BHV1 outbreaks' of a farm which allowed rejected export cattle to return on the farm was 4.59 times higher than of a farm which did not. The 'rate of BHV1 outbreaks' of a farm which had an occasional visitor in the barn at least once a week was 2.56 times higher than of a farm that had visitors less often. One extra visit from a professional visitor increased the 'rate of BHV1 outbreaks' by 1.01.

Table 1: Multivariable Cox regression model of risk factors related to introduction of BHV1 into dairy farms (n = 50, overall score = 14.7, P= 0.02)

Variables	ß	se	*P*	HR	90%CI
# of cattle purchased in 1995	0.12	0.05	0.02	1.13	1.04-1.23
Rejected export cattle returned on the farm in 1995	1.52	0.62	0.01	4.59	1.65-12.82
At least once a week an occasional visitor (e.g. neighbours, family, friends) in the barn	0.94	0.55	0.09	2.56	1.04-6.32
# of professional visitors on a farm per year	0.01	0.00	0.06	1.01	1.00-1.01

5.3.1.2 Survival analysis of risk factors related to successful reactivation

In the univariable Cox regression five management factors related to possible reactivation of BHV1 at the farm were related to the 'rate of BHV1 outbreaks' with $P \leq 0.25$. These variables were 'having a bull', 'more cows than cubicles in the barn', 'cleaning separate calving and/or sick stable with a high-pressure hose', ' participation in a veterinary herd health program', and 'cattle intensity on grassland'. These variables were not correlated. The final model resulting from the multivariable Cox regression of management factors is shown in Table 2. No two-way interaction terms were found significant.

Table 2: Multivariable Cox regression model of management factors for reactivation of BHV1 at dairy farms (n = 50, overall score = 6.0, P = 0.05)

Variables	ß	se	P	HR	90%CI
More cows than cubicles in the barn	1.29	0.67	0.06	3.63	1.20-11.00
Cleaning separate calving and/or sick stable with a high-pressure hose	0.96	0.52	0.06	2.60	1.11-6.08

In the multivariable model two management factors related to reactivation of BHV1 at the farms were related to the 'rate of BHV1 outbreaks'. When the barn is overcrowded ('more cows than cubicles in the barn') the 'rate of BHV1 outbreaks' increased 3.63 times compared with a farm which had enough or more cubicles than cows. A farm which cleaned the separate calving or sick stable with a high-pressure hose had a 2.60 times higher 'rate of BHV1 outbreaks' than a farm which did not clean or did not have separate stables.

5.3.1.3 Survival analysis of risk factors for both introduction and reactivation

All management and risk factors were included in the full model. Some variables were correlated with each other. These were 'more cows than cubicles in the barn' and '# of professional visitors on the farm' ($r = 0.34$, $P = 0.02$); 'cleaning separate calving and/or sick stable with a high-pressure hose' and 'a temporary worker who also works on other farms' ($r = 0.36$, $P = 0.01$); and 'rejected export cattle returned on the farm' and 'cattle intensity on grassland' ($r = 0.45$, $P = 0.00$). Because none of the correlations exceeded 0.50, all variables were offered to the full model. The results of the multivariable Cox regression are shown in Table 3. No two-way interaction terms were found statistically significant.

Table 3: Multivariable Cox regression model of all management and risk factors on dairy farms (n = 50, overall score = 19.5, P = 0.00)

Variables	ß	se	P	HR	90%CI
# of cattle purchased in 1995	0.09	0.05	0.06	1.10	1.01-1.19
Rejected export cattle returned on the farm	1.73	0.64	0.01	5.63	1.98-16.10
At least once a week an occasional visitor (e.g. neighbours, family, friends) in the barn	1.08	0.57	0.06	2.95	1.15-7.56
More cows than cubicles in the barn	1.78	0.83	0.03	5.94	1.52-23.26
Cleaning separate calving and/or sick stable with a high-pressure hose	1.24	0.56	0.03	3.47	1.39-8.66

Only 'the number of professional visitors on a farm per year' did not remain in the final model. The other risk factors and management factors found significant in the first two models were also significant in the combined model.

5.3.2 Sensitivity analysis

Four farms were excluded because of extreme values of the 'rate of BHV1 outbreaks'; two cases and two censored cases. All three models (introduction, reactivation and combined) were recalculated and the outcomes did not show an important difference from the original models. In the introduction model, 'occasional visitors' became non-significant ($P = 0.15$); the other variables remained significant ($P \leq 0.10$) and the HRs became slightly lower. In the reactivation model the HRs also became slightly lower but all variables remained significant ($P \leq 0.10$). The same applied for the combined model; all variables remained significant at $P \leq 0.10$, also with slightly lower HRs.

5.4 Discussion

Cox regression analysis proved to be a satisfying tool to analyse the relationship between management and the rate of BHV1 seroconversions. When, more commonly, a dichotomous dependent variable had been used (the farm was positive or negative for BHV1), information about differences in prevalence on the BHV1-positive farms would not be used, nor the time since latest (possible) outbreak. The information in the current study was increased by using the prevalence and age distribution of BHV1 antibodies on a farm. Information of BHV1-negative farms was also included, because for both BHV1-positive and negative farms the incidence versus the prevalence of BHV1-seroconversion was estimated. The extra information of the BHV1-negative farms incorporated in the dependent variable made it possible to find significant relationships with management and risk factors, although the number of case farms was limited (see Table 3).

The objective of the present paper was to investigate why some farms did not have or had fewer new introductions or reactivations of BHV1. The management factors influencing new introductions and/or reactivations of BHV1 were investigated. The risk factors found in this study were partly the same as found by Van Schaik et al. (1998). This is not surprising since the 50 farms were a subgroup of the 107 farms investigated by Van Schaik et al. (1998).

In the present study 'purchase of cattle' had almost the same HR (1.10) as in the previous study by Van Schaik et al. (1998) (OR = 1.12). Another risk factor found in both studies was 'occasional visitors' which, in the present study, had an HR of almost three, which was lower than in the previous study by Van Schaik et al. (1998). The present study stressed the importance of these two risk factors. A risk factor that was not found in the previous study by Van Schaik et al. (1998) was 'returning export cattle' (HR = 5.63). In the Netherlands, cattle that are sold for export are often gathered in specialized barns. This gathering of large numbers of cattle in an unfamiliar (stressful) environment will facilitate the spread of infectious diseases between these cattle. Sometimes when there are surplus export cattle, they are returned to the farm of origin and may infect other cattle on the farm.

The dependent variable in the present study was not only used to investigate the risk factors for introduction of BHV1 but also for reactivation of BHV1 at the farm. The HR of an overcrowded barn ('more cows than cubicles in the barn') was quite high (3.63), implying that an overcrowded barn facilitates new introductions or reactivations of BHV1 at the farm. An overcrowded barn can only occur in loose housing systems. The causative factor for reactivation of BHV1 in such a barn might be that an overcrowded barn leads to higher stress levels of the cows and more contacts between the cows. The HR of 'cleaning separate calving and/or sick stable with a high-pressure hose' was also larger than one (2.60). A high-pressure hose might distribute virus (droplet-infection), and calving is a time of high risk of reactivation. 'Cleaning separate calving and/or sick stable with a high-pressure hose' was also significantly correlated with 'loose housing system' (r = 0.38, P = 0.01). Both variables were included in the full model but 'loose housing system' did not remain in the final model. The variable 'loose housing system' was thought to be a confounder for 'cleaning separate calving and/or sick stable with a high-pressure hose'. Farms with a loose housing system more often have a separate stable for calving or diseased cows than farms with a tied housing system. In a loose housing system compared with a tied stall higher stress levels of the cows might lead to more reactivation of BHV1.

5.4.1 Limitations

In the questionnaire we asked the farmer only about management of the past five years. The farmer might however only remember the management of the most recent years (recall bias). In recent years the farming system in the Netherlands has become more closed. The maximum time since the latest seroconversion was, however, almost 15 years ago, when the management may have been different and the farm was more open. The results of the present study might therefore underestimate the importance of the risk and management factors causing introduction and/or reactivation of BHV1.

The dependent variable 'rate of BHV1 outbreaks' is based on a number of assumptions. Cattle that are infected with BHV1 keep a lifelong positive status for BHV1, which is assumed by Ackermann et al. (1990a) and Hage (1997). However, the tests cannot distinguish between naturally infected cows and cows with antibodies due to non-marker vaccines and the dependent variable might include both. The 50 farms in this study said that they had never vaccinated against BHV1 but might have purchased cattle that had been vaccinated. A (purchased) cow, which was naturally infected might re-shed the virus in stressful situations (Hage, 1997), such as when entering a new herd. This cow might then infect the whole herd. When a cow is positive for BHV1 by (live) vaccination, reactivation does not occur very frequently. The HR of the purchase of cattle may be based on both non-vaccinated and vaccinated cows and therefore underestimates the risk of introduction of BHV1.

We also assumed that most outbreaks lead to complete spread of BHV1 in the milking herd (Hage, 1997). When all cattle are seropositive a new introduction or reactivation can not occur. Only when new seronegative heifers are introduced in the milking herd new infections can occur. Therefore, a herd will be less susceptible for a BHV1 infection just after a BHV1 outbreak. This falsifies the assumption of a constant rate of introduction and reactivation, but only for a limited period. As soon as sufficient seronegative animals are introduced in the herd the herd is susceptible again. Dutch dairy herds have an average replacement rate of 30% (Dutch Cattle Syndicate). A year after the outbreak the herd will contain enough susceptible animals to have a considerable chance of seroconversion again. We assumed that the impact of the less susceptible period is small relative to the rare event of BHV1 introduction or reactivation at Dutch dairy farms (Hage et al., 1998; Nieuwstadt and Verhoeff, 1983; Vonk Noordegraaf et al., 1998). The impact of the less susceptible period will be that the rate of introduction or reactivation is only slightly underestimated.

In the case of a minor outbreak we also underestimate the rate of introduction or reactivation of BHV1. For example, if one 14-year-old cow had become infected one year ago and other cows were not infected, we assumed that the outbreak occurred 14 years ago. However, the impact should be small because only 15% of the outbreaks is minor and even in a minor outbreak more than one cow will become infected.

5.4.2 Concluding remarks

The present study was retrospective and had a few limitations such as recall bias and underestimation of the rate of introduction and reactivation. Significant associations have been made visible, but causal relationships have not been proven with the present study. However, the relationships might be causal because they fit in with current knowledge. In a follow-up study these limits might be overcome by looking at farms prospectively. In a prospective follow-up study BHV1-free farms with a management that is known can be investigated as to introduction and spread of BHV1. Such a study is currently being carried out and results might reveal more of the relationships between management and introduction of BHV1.

The results of the present study show that farmers can minimize the risk of introduction of BHV1 considerably by banishing direct animal contacts. Contacts of cattle with visitors cannot be avoided completely and the risk of these contacts should therefore be minimized as much as possible (e.g. by providing protective clothing to visitors). Furthermore, a farmer might reduce the magnitude of reactivation of BHV1 at the farm as much as possible by avoiding an overcrowded barn.

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References

Ackermann, M., Müller, H.K., Bruckner, L. and Kihm, L., 1990a. Eradication of infectious bovine rhinotracheitis in Switzerland: review and prospects. *Veterinary Microbiology* 23: 365-370.

Ackermann, M., Weber, Hp., Wyler, R., 1990b. Aspects of infectious bovine rhinotracheitis eradication programmes in a fattening cattle farm. *Preventive Veterinary Medicine* 9: 121-130.

Bosch, J.C., 1997a. Bovine Herpesvirus 1 marker vaccines: tools for eradication? PhD thesis, Utrecht University, 122 pp.

Bosch, J.C., De Jong, M.C.M., Franken, P., Frankena, K., Hage, J.J., Kaashoek, M.J., Maris-Veldhuis, M.A., Noordhuizen, J.P.T.M., Van der Poel, W.H.M., Verhoeff, J., Weerdmeester, K., Zimmer, G.M., and Van Oirschot, J.T., 1998. An inactivated gE-negative marker vaccine and an experimental gD-subunit vaccine reduce the incidence of bovine herpesvirus 1 infections in the field. *Vaccine* 16, 1-2: 265-271.

Cox, D.R., 1972. Regression models and life tables. *Journal of Research of the Statistical Society* 34: 187-202.

Hage, J.J., 1997. Epidemiology of bovine herpesvirus 1 infections. PhD thesis, Utrecht University, 212 pp.

Hage, J.J., Schukken, Y.H., Schols, H., Maris-Veldhuis, M.A., Rijsewijk, F.A.M., and Klaassen, C.H.L., 1998. Transmission of bovine herpesvirus 1 within and between herds on an island with a BHV1 control programme. Submitted.

Kleinbaum, D.G., 1996. Survival analysis: a self-learning text. Springer series in statistics. Statistics in the health sciences, Edward Brothers, Inc., Ann Arbor, MI, 324 pp.

Kramps, J.A., Magdalena, J., Quak, J., Weerdmeester, K., Kaashoek, M.J., Maris-Veldhuis, M.A., Rijsewijk, F.A.M., Keil, G., and Van Oirschot, J.T., 1994. A simple, specific, and highly sensitive blocking enzyme-linked immunosorbent assay for detection of antibodies to bovine herpesvirus 1. *Journal of Clinical Microbiology* 32: 2175-2181.

Msolla, P.M., Wiseman, A. and Selman, I.E., 1981. The prevalence of serum neutralised antibodies to infectious bovine rhinotracheitis virus in Scotland. *Journal of Hygiene* 86: 209-215.

Norusis, M.J., 1994. SPSS Advanced Statistics 6.1. SPSS inc., Chicago, 606pp.

Pastoret, P.-P., Thiry, E., Brochier, B., Derboven, G. and Vindevogel, H., 1984. The role of latency in the epizootiology of infectious bovine rhinotracheitis. In: Wittmann, G., Gaskell, R. and Rziha, H.-J. (Eds), Latent Herpesvirus Infections in Veterinary Medicine. Martinus Nijhoff Publishers, The Hague, 211-228.

Thomsen, B.L., Jorsal, S.E., Andersen, S. and Willeberg, P., 1992. The Cox regression model applied to risk factor analysis of infections in the breeding and multiplying herds in the Danish SPF system. *Preventive Veterinary Medicine* 12: 287-297.

Van Schaik, G., Dijkhuizen, A.A., Huirne, R.B.M., Schukken, Y.H., Nielen, M., Hage, J.J., 1998. Risk factors for existence of Bovine Herpesvirus 1 antibodies on non-vaccinating Dutch dairy farms: an exploratory study. *Preventive Veterinary Medicine* 34: 125-136.

Van Wuijckhuise, L., Bosch, J., Franken, P., Hage, J.J., Verhoeff, J. and Zimmer, G., 1993. The prevalence of infectious Bovine Rhinotracheitis (IBR) in the Netherlands. In: Elbers, A.R.W. (Ed), *Proceedings of the 6th meeting of the Dutch Society for Veterinary Epidemiology and Economics*. Boxtel, 7-16.

Verhoeff, J. and Van Nieuwstadt, A.P.K.M.I., 1984. BRS virus, PI3 virus and BHV1 infections of youngstock on self-contained dairy: Epidemiological and clinical findings. *The Veterinary Record* 114: 288-293.

Vonk Noordegraaf, A., Buijtels, J.A.A.M., Dijkhuizen, A.A., Franken, P., Stegeman, J.A., Verhoeff, J., 1998. An epidemiological and economic simulation model to evaluate the spread and control of infectious bovine rhinotracheitis in the Netherlands. *Preventive Veterinary Medicine* 36: 219-238.

Wentink, G.H., Van Oirschot, J.T. and Verhoeff, J., 1993. Risk of infection with bovine Herpesvirus 1 (BHV1): a review. *Veterinary Quarterly* 15: 30-33.

Wiseman, A., Msolla, P.M., Selman, I.E., Allan, E.M. and Pirie, H.M., 1980. Clinical and epidemiological features of 15 incidents of severe infectious bovine rhinotracheitis. *The Veterinary Record* 107: 436-441.

Appendix

Table A: Categorical risk factors for introduction of BHV1 at the farm tested in univariable Cox regression analysis at $P \leq 0.25$.

Risk factors	Level	no. of farms	% BHV1-positive
Sharing pasture	Cattle grazing on other farms (1)	7	0.0
	Not practised (0)	43	39.5
Occasional visitors[a]	At least once a week an occasional visitor (e.g. neighbours, family, friends) in the barn (1)	12	50.0
	Less than once a week (0)	38	28.9
Temporary workers[a]	A temporary worker who comes into contact with cows from other farms (1)	7	71.4
	No temporary worker on the farm or worker does not come into contact with cows from other farms (0)	43	27.9
Returning export cattle[a]	Cattle sold for export return from the export-stables (1)	7	57.1
	No export cattle sold or cattle never return on the farm (0)	43	30.2
Embryo transplantation	Embryo transplantation carried out on the farm (1)	3	29.8
	No embryo transplantation in 1990-1995 (0)	47	100.0
Nose-to-nose contacts	Nose-to-nose contacts over the fence are possible with cattle from other farms (1)	14	35.7
	No such contacts possible (0)	36	33.3
Use of AI only	Only Artificial Insemination used to breed the cows (1)	26	34.6
	A bull is also used to breed the cows (0)	24	33.3
Cattle breach or escape	Cattle breach or escape from their confined areas and mingle with other herds (1)	22	31.8
	Cattle never breach or escape from their confined areas (e.g. pasture) and do not mingle with other herds (0)	28	35.7
Presence of protective clothing and/or boots	Visitors (e.g. veterinarians) have to wear protective clothing or disinfect their boots when entering the barn (1)	10	40.0
	Visitors do not take precautionary measures when entering the barn (0)	40	32.5

[a] $P \leq 0.25$ in univariable Cox regression analysis

Table B: Categorical risk factors for reactivation of BHV1 at the farm tested in univariable Cox regression analysis at $P \leq 0.25$.

Variables	Level	no. of	% BHV1-
General and housing factors			
Barn	Loose housing	38	39.5
	Tied housing	12	16.7
Housing of youngstock until 1 year old	In the same barn as the cows	22	31.8
	Not in the same barn as the cows	28	35.7
Housing of heifers from 1 year old	In same barn as the cows	43	37.2
	Not in same barn as cows	7	14.3
Cattle density in the barn[a]	More cows than cubicles	5	60.0
	Equal or fewer cows than cubicles	45	31.1
Separation of calving or diseased cows	No separate stables for calving and diseased cows	11	27.3
	Separate stable for both calving and diseased cows	20	45.0
	Separate stable for diseased and separate stable for	19	26.3
Bull[a]	Present	22	26.1
	Absent	27	40.7
Other animal species present			
Sheep	Present	15	40.0
	Not present	35	31.4
Dogs	Present	27	33.3
	Not present	23	34.8
Cats	Present	32	31.3
	Not present	18	38.9
General management factors			
Veterinary herd health program[a]	Participation	10	60.0
	No participation	40	27.5
Cleaning procedures			
Housing of calves	Cleaning after every use	16	41.7
	Not cleaning after every use	34	31.6
Cubicles of cows	Cleaning of manure	33	36.4
	No cleaning	17	29.4
Separate calving and/or sick stable[a]	Stable is present and cleaned with a high-pressure	21	47.6
	No stable or stable not cleaned with a high-	29	24.1

[a] $P \leq 0.25$ in univariable Cox regression analysis

Table C: Continuous risk factors for introduction and reactivation tested in univariable Cox regression analysis at P ≤ 0.25.

Variable	BHV1-positive (n = 17)			BHV1-negative (n = 33)		
	25% perc.	median	75% perc.	25% perc.	median	75% perc.
Risk factors for introduction						
Distance to nearest other cattle farm (m.)	187.5	300.0	500.0	225.0	350.0	500.0
Number of cattle purchased in a year[a]	0.0	2.0	6.5	0.0	1.0	3.0
Number of cows which were taken to a cattle show in 1995[a]	0.0	0.0	1.0	0.0	0.0	0.0
The number of professional visitors on a farm per year[a]	89.0	180.0	249.0	95.0	131.0	193.5
Risk factors for reactivation						
Number of cows	42.5	50.0	59.5	27.0	46.0	61.5
Cattle intensity on grassland (cattle/ha)[a]	2.8	3.3	3.6	2.7	3.1	3.8

[a] P≤ 0.25 in univariable Cox regression analysis

Chapter 6

Risk factors for introduction of BHV1 into BHV1-free Dutch dairy farms: A case-control study.

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Abstract

In May 1998 a compulsory eradication program for BHV1 started in the Netherlands. In December 1999 approximately 24% of the Dutch dairy farms were certified BHV1-free (Animal Health Service (AHS)). Ninety-three certified BHV1-free dairy farms participated in a cohort study that investigated the probability of introduction of infectious diseases. The probability of introduction of BHV1 was measured from the start of the study in March 1997 until the end of the study in April 1999. Ninety of these farms remained BHV1-free and could be used as control farms. From January 1997 until March 1998 BHV1 was introduced into 44 BHV1-free dairy farms in the Netherlands (outbreak farms). Management data were collected on both cases and controls and the data sets (90 follow-up farms and 44 outbreak farms) were combined in one data set to be analysed together. For small data sets, and for data in which both small and large frequencies are expected in the contingency tables, the asymptotic methods are unreliable. Our data set clearly resembled such a data set; the risk factors were rare events because the BHV1-free farms were closed farms on which little direct animal contacts occurred. Therefore, an exact stratified modelling approach was most suitable for the data. The study showed that direct animal contacts and professional visitors were risk factors for introduction of BHV1. Dairy farms should prevent cattle to breach or escape and mingle with other cattle and have professional visitors always wear protective farm clothing.

6.1 Introduction

BHV1 (Bovine Herpesvirus type 1) causes the disease called infectious bovine rhinotracheitis as well as infectious pustular vulvovaginitis and was introduced in the Netherlands in 1971 (Vonk Noordegraaf et al., 1998). In the near future, stricter requirements are expected in the European Union (and other countries) regarding the health status of imported breeding cows and material. Therefore, there is an increasing need to eradicate diseases such as BHV1 in exporting countries such as the Netherlands (Vonk Noordegraaf et al., 1998). A previous study of Van Schaik et al. (1998a) showed that the presence of BHV1 on dairy farms was related to several types of risk factors (e.g. direct animal contacts and visitors). The results of this previous study were based on data concerning 1995. At that time it was not known yet whether an eradication program for BHV1 was going to be implemented. Therefore, farmers and their advisers were not always conscious of the risk factors for introduction of BHV1 (Van Schaik et al., 1998b). Furthermore, the 1995 study might have been partly biased, because the time span between introduction of BHV1 and the questionnaire was unknown (Van Schaik et al., 1998a).

In May 1998 a compulsory eradication program for BHV1 started in the Netherlands. Farms can obtain a certified BHV1-free status by testing all cattle individually for antibodies against BHV1. All seropositive cattle need to be culled and subsequently farms obtain the BHV1-free certificate. Farms of which more than 10% of the cattle is BHV1-positive have to vaccinate for BHV1 twice a year with a live marker vaccine. The status of the certified BHV1-free farms is evaluated by monthly bulk-milk samples. When a positive sample occurs, the farm obtains an observation status and the bulk milk is resampled. A second seropositive sample confirms a BHV1 outbreak and the farmer has to vaccinate all cattle. In December 1999 approximately 24% of the 30,000 Dutch dairy farms were certified BHV1-free (Animal Health Service (AHS)). The present study will focus on risk factors for introduction of BHV1 into certified BHV1-free farms. Certified BHV1-free farms made considerable (financial) efforts to obtain their certificate. They are expected to be more risk-averse concerning introduction of BHV1 than the farms in the previous study in 1995 (Van Schaik et al., 1998a). The objective of the study was to obtain risk factors for introduction of BHV1 into certified BHV1-free farms. The results of this study can be used to develop a more closed farming system to prevent introduction of BHV1. A country or region will become BHV1-free faster when farmers adopt a more closed farming system, which will decrease the total time and costs of the national eradication program (Vonk Noordegraaf et al., 1998). With a more closed farming system farmers can also prevent economic losses as a result of a BHV1 introduction into their own farms (Van Schaik et al., 1999).

6.2 Materials and methods

6.2.1 Farms

Ninety-three dairy farms participated in a cohort study that investigated the economic consequences of a more closed farming system to prevent introduction of infectious diseases. All farms were certified free of BHV1 at the start of the project in March 1997. The incidence of introduction of BHV1 was measured until the end of the study in April 1999. Management data and data on mastitis incidence and fertility were collected on the farms with 6-month intervals, by the senior author or well trained students. Farmers registered the data during these 6-monthly periods and during the farm visits the data were verified and discussed. This resulted in very detailed data on direct animal contacts (e.g. purchase of cattle), contacts by professional visitors (use of protective clothing) and the BHV1-status of neighbouring farms. The 93 certified BHV1-free dairy farms (follow-up farms) were a sub-sample of all BHV1-free farms in the northern provinces of the Netherlands. In the sub-sample of 93 dairy farms three farms experienced an introduction of BHV1 in the period March 1997 until 1998 and were treated as case farms.

From January 1997 until March 1998 all Dutch BHV1-free farms at which BHV1 was introduced (outbreak farms) were visited by a veterinarian of the AHS. A questionnaire was filled out to obtain possible causes for the outbreak at the farm. The questionnaire focused on the possible causes of the introduction in the previous three to six months. Data were collected on BHV1 history, direct animal contacts (e.g. purchase of cattle), contacts by professional visitors (use of protective clothing) and the BHV1 status of neighbouring farms. Fifty-seven cattle farms of which 44 dairy farms had a BHV1 outbreak and were visited by the AHS (including the three cohort study farms). Only dairy farms were included in the analysis. Both data sets (90 follow-up farms and 44 outbreak farms) were combined to be analysed together. In the period that data were collected at the outbreak farms, the follow-up farms were visited three times. The outbreak farms were therefore divided in three groups; an introduction of BHV1 before April 1st 1997, an introduction of BHV1 between April 1st and October 1st 1997, and an introduction of BHV1 between October 1st 1997 and April 1st 1998. Seven outbreak farms were excluded from the analysis since they lost their BHV1-free status already within six weeks after obtaining it. It was assumed that these farms were never completely BHV1-free (Van Schaik et al., 1999). Four outbreak farms had an outbreak in the first period, 20 farms had an outbreak in the second period, and also 20 farms had an outbreak in the third period. For every time period controls were randomly selected based on the ratio of cases in that time period (e.g. in the first time period 4/44*90= 8 controls were selected). A control could be selected only once and the other observations of a control were discarded. Every time period has its own specific management, e.g. in summer farms will graze cattle but not in winter. Forcing the same ratio of outbreak and non-outbreak farms in every time period prevented bias due to different management in different periods.

6.2.2 Data analysis

The rate of BHV1 outbreaks in the Netherlands was calculated using data of the AHS. The number of certified BHV1-free dairy farms was reported every three months by the AHS. The number of outbreaks was calculated over a three-month period, the month in which the AHS reported the number of certified BHV1-free dairy farms, the preceding and the following month. The rate of BHV1 outbreaks was calculated as the number of outbreaks in the three-month period divided by the average number of certified BHV1-free dairy farms at risk in that period.

Descriptive statistics were carried out in SPSS 9.0. Independent-sample t-test was used for continuous variables and a two-sided Fisher's exact test was used for categorical variables to test the association with an outbreak of BHV1 by a liberal *P*-value of 0.25 (Hosmer and

Lemeshow, 1989). Some variables were tested as continuous as well as dichotomous variables. Categorical variables with more than two categories were transformed into two or more dummy variables and compared by Fisher's exact test on BHV1 outbreak. This was done to determine whether distinction among the categories was important. Based on these results two or more categories could be combined with minimal loss in predictive ability and the final categorical variables only consisted of two categories. The results of the univariable analysis were used in further multivariable analysis. Statistical significance was defined at $P<0.10$ and a trend was assumed when $P<0.25$.

In the second part of the analysis logistic regression was used to analyse the multivariable relationships between risk factors and BHV1 outbreak, including interaction terms (Hosmer and Lemeshow, 1989). The statistical analysis was carried out by using logistic regression (Test Exact and Estimate Exact) in LogXact (Mehta and Patel, 1993). Both a stratified analysis on the time period in which the farms were grouped and an unstratified analysis were carried out. Exact conditional parameters were estimated and point estimates, mid P-values (Lancaster, 1961), odds ratios (OR), and attributable proportions (AP) are reported. Additionally the asymptotic P-value is presented for comparison with the mid P-value.

Odds ratios from the univariable analysis were compared with those from the multivariable analysis. If those odds ratios differ considerably the variable might be a confounder or interaction term. Collinearity between the variables was investigated by means of the bivariate exact correlation coefficients. In the "starting" multivariable model, all risk factors were offered initially. The risk factors initially offered to the model were excluded from the model with a conditional backward elimination procedure, and then the possible interaction terms were investigated with a forward conditional selection procedure. Risk factors and interaction terms were entered in the model at $P<0.05$ and removed at $P>0.10$. Outliers with a standardised residual larger than 2 were investigated.

6.3 Results

6.3.1 BHV1 situation in the Netherlands

Figure 1 shows that the number of certified BHV1-free dairy farms rapidly increased from 400 in January 1997 until 3900 in April 1998. Figure 2 shows that the number of outbreaks during the study period was highest in October 1997, 17 farms. The rate of outbreaks per 10000 dairy farms at risk in a three-month period varies between 21 and 80 farms.

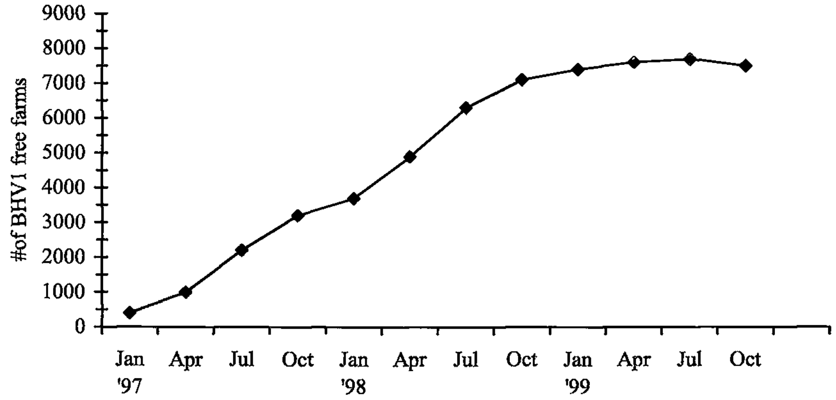

Figure 1: The number of certified BHV1 free dairy farms in the Netherlands (source: Animal Health Service)

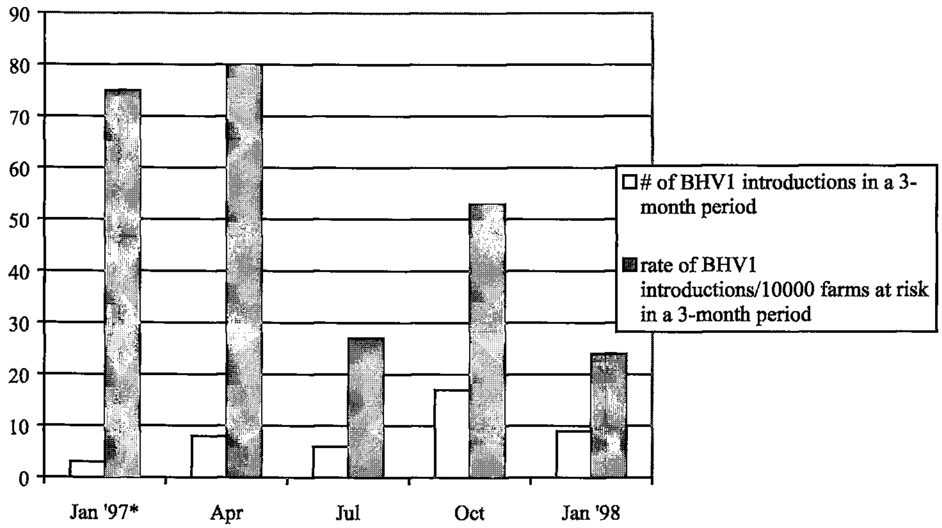

Figure 2: The absolute number and rate per 10000 dairy farms at risk of BHV1 introduction at BHV1 free dairy farms in three months from Jan. '97 till Feb. '98. * The number of outbreaks of one of the three months is estimated

6.3.2 Univariable analysis

The control farms had significantly more milking cows (50 versus 42) and a higher 305-day milk production (8174 versus 7900) than the case farms. Fifteen farms were excluded from the analysis because of missing data, no information was available on one or more risk factors, 13 farms missed information on cattle that breached or escaped. What remained were 82 non-outbreak farms and 37 outbreak farms. The definition of a professional visitor in this study was people that come in contact with cattle (e.g. veterinarians, AI technician, and cattle traders). The variable "professional visitors always use protective farm clothing" consisted of three categories; professional visitors do not use it, sometimes use it, and always use it. The variable was transformed in two categories; not or sometimes, and always using protective farm clothing. The BHV1 status of neighbouring farms was often unknown by both the case and the control farmers and could therefore not be included in the analysis. The distance in metres to the nearest other cattle farm is an estimate of the farmer, and was not significantly different between outbreak (347m.) and non-outbreak farms (354m.). Controls participated in a follow-up study in which very detailed data were collected. The cases where only visited once to administer a questionnaire, and the data were much less detailed. For example, the type of cattle (i.e. milking cows or youngstock) with which over the fence contacts or mingling occurred was known from the cattle of controls but not from the cases. Therefore, the analysis could not be as detailed for every risk factor as desired.

The remaining variables were all binary variables. Milking cows or youngstock breach from their plots and mingled with other cattle or did not, a farmer participated with cattle in a cattle show or did not, cattle had the possibility for nose to nose contacts over the fence with other cattle or did not, purchased BHV1-free cattle or did not purchase cattle, rejected cattle was allowed by the farmer to return on the farm after being sold for e.g. export or breeding or was not, and cattle was grazed on other farms or other cattle was grazed on the own farm or was not.

Table 1: Exact univariable analysis of risk factors for introduction of BHV1 into BHV1-free Dutch dairy farms.

Risk factors	Non-outbreak farms (n=82)	Outbreak farms (n=37)	Fishers'Exact P-value
Professional visitors always use protective farm clothing	49.5%	26.8%	0.02
Milking cows breached or escaped and mingled with other cattle	1.2%	8.1%	0.09
Participation in cattle shows	1.1%	5.0%	0.22
Over the fence contacts with other cattle are possible	25.3%	29.7%	0.66
Youngstock breached or escaped and mingled with other cattle	8.5%	11.4%	0.73
Purchase of BHV1-free cattle	7.7%	10.0%	0.74
Allowing cattle to return at the farm	2.2%	0.0%	1.00
Grazing cattle at other farms or other cattle at own farm	3.3%	2.5%	1.00

None of the variables of the univariable analysis had a correlation coefficient larger than 0.50 with any of the other variables. Table 1 shows a part of the results of the univariable analysis of the risk factors for introduction of BHV1. Risk factors with an empty cell in the two-by-two table are not presented.

Only 2 risk factors were significant in the exact univariable analysis, "milking cows breached or escaped and mingled with other cattle" and "professional visitors always used protective farm clothing". Outbreak farms also seemed to participate in cattle shows more frequently. The only risk factor concerning direct animal contacts that was relatively common at both the non-outbreak and the outbreak farms was "over the fence contacts with other cattle".

6.3.3 Multivariable analysis

The stratified analysis resulted in a better model than the unstratified analysis, the likelihood ratio was significantly lower (26.6 versus 7.2) and therefore the results of the stratified multivariable analysis are presented in Table 2. No interaction terms were found to be significant and no confounders were found.

Table 2: Results of the stratified multivariable analysis of the risk factors for introduction of BHV1 into BHV1-free Dutch dairy farms.

Risk factors	β	Mid P-value	Asymptotic P-value	OR	AP
Intercept	-0.47	Ns	Ns	-	-
Professional visitors always use protective farm clothing	-0.85	0.06	0.07	0.43	0.46
Milking cows breached or escaped and mingled with other cattle	1.92	0.05	0.10	6.85	0.07

likelihood ratio = 7.2, 2 df, Hosmer and Lemeshow statistic = 0.03, P = 0.86.

The final model (Table 2) correctly classified 74% (88/119) of the farms for a BHV1 outbreak. However, only 19% (7/37) of the outbreak farms were correctly classified compared with 99% (81/82) of the non-outbreak farms. Ten of the 31 incorrectly classified farms were outliers. All 10 outliers but one were outbreak farms that had protective farm clothing that was always used by professional visitors, and no milking cows breached or escaped. Since these were the only risk factors in the final model, these farms could not be classified correctly by the model.

6.4 Discussion and conclusions

6.4.1 BHV1 in the Netherlands

The number of certified BHV1-free dairy farms rapidly increased from 400 in January 1997 until 7500 in December 1999, which is 24% of the Dutch dairy farms. The rate of BHV1 introductions seemed to become lower. A possible explanation is that the farms that were most at risk because of their management were the first to experience introduction of BHV1. During the study period from January 1997 until April 1998 a more closed farming system was promoted intensively. Therefore, an increased number of farmers might have adopted a more closed farming system during that year, which would have decreased the rate of BHV1 introductions. Another explanation might be that the infection pressure of BHV1 declined as a result of the increased number of BHV1-free farms. There was a more than 10-fold increase of BHV1-free farms from January 1997 until April 1998. The effect of reduced BHV1 transmission due to vaccination is expected to be small since the compulsory vaccination on infected farms started in May 1998.

6.4.2 Risk factors for introduction of BHV1.

The most important risk factor found in the present study was when professional visitors (e.g. veterinarians, AI technicians) do not or not always use protective farm clothing when handling cattle. Seventy-three percent of the outbreak farms did not have protective farm clothing for professional visitors or the visitors were not always using it. The prevented fraction of 0.46 supports the importance of providing professional visitors with protective farm clothing. Almost half of the new cases are attributable to this risk factor. The other significant risk factor was "cattle breached or escaped and mingled with other cattle" (AP = 0.07). Although only 7% of the cases are attributable to this risk factor dairy farmers should avoid this direct animal contact. Nylin et al. (1998) also found direct animal contacts to be the major source of introduction of BHV1 at BHV1-free dairy farms in Denmark.

In the present study the risk factor "youngstock breach or escape" was not found to be significant. This might imply that contacts of adult cattle are more risky than contacts of youngstock with other cattle. The seroprevalence in dairy herds is often found to be dependent on the age of cattle. Youngstock is seronegative, milking cows are more often seropositive (Van Wuijckhuise et al., 1993). From the case farms it was not known with which age group escaped cattle mingled. However, escaped youngstock seemed to be less likely to pick up or transmit BHV1 to the own herd. Another explanation might be that when youngstock seroconvert for BHV1 this will only be detected after some time, when they infect milking cows or when they start to lactate themselves. The status of certified BHV1-free dairy farms is monitored by monthly bulk milk samples.

The other causes of the BHV1 outbreaks were less clear. We expect that the other outbreaks were caused by a variety of risk factors, such as participation in cattle shows (5% of the outbreak farms), over the fence contacts with cattle (30% of the outbreak farms), and purchase of cattle (10% of the outbreak farms). The fact that these risk factors were not found to be significantly different between outbreak and non-outbreak farms might be caused by their rare occurrence and by extra management measures. However, only the data obtained from the control farms was very detailed with respect to the origin, the disease status, and transport of e.g. purchased cattle. Certified BHV1-free farms are only allowed to purchase cattle from BHV1-free farms, so cattle can become infected during transport when mingled with other cattle. A farmer who takes extra measures such as transport in his/her own, clean truck and without other cattle has less chance of introducing BHV1 at the farm. Data on management quality was mostly missing for the cases and could therefore not be included in the analysis. Unfortunately, the power of the study limited inclusion of the extra management measures that were available and that might have reduced the risk of the risk factors. The risk factors and the management measures were too infrequent.

The chance of infection might also be dependent on the BHV1 status of neighbours. When neighbouring farms are not BHV1-free, over the fence contacts or escaping cattle are more risky than when neighbouring farms are also BHV1-free. However, both cases and controls were often not aware of the BHV1 status of neighbouring cattle. Over the fence contacts was not found to be a significant risk factor, but might have been when corrected for the BHV1 status of neighbours.

In the present study the distance to other cattle farms was not found to be a significant risk factor contrary to a previous study of Van Schaik et al. (1998). The mean distance in the present study was larger than in the previous study, which might explain the fact that distance was not found to be a risk factor. There might be a critical distance for spread of BHV1 between farms, just like there is a critical distance for spread of other diseases (Stärk, 1999). However, the critical distance for BHV1 transmission between farms is not known exactly (Nylin et al., 1998; Mars et al., 1999).

Analysis by the AHS also showed that on many outbreak farms the case of introduction could not be established. Obviously, not all risk factors of introduction are clearly understood or quantifiable. Possibly, "neighbourhood infections", as clearly found in exotic disease outbreaks (CSF, FMD) might play a role for BHV1 too. Other factors such as non-professional visitors that have contact with cattle might be important as well. These contacts were not recorded in the present study, but in another study they were found to be numerous (Nielen et al., 1996). Information was also missing on cattle trucks, milk trucks, or destruction trucks that had visited the farm, on rodents or bird control, and on cats, dogs, or other animal species that might have played a role in BHV1 transmission.

6.4.3 Bias

Seven case farms were excluded from the study since introduction of BHV1 was most likely to have occurred within six weeks after they became officially BHV1-free. We assumed that these farms did not have an introduction of BHV1 but had not been truly BHV1-free from the start. We assumed farms to have truly introduced BHV1 when a seropositive bulk-milk sample was found after a farm had been seronegative for at least six weeks. We might have misclassified some farms, some of the excluded farms might truly have had a new introduction of BHV1 and some of the retained farms might not have been truly BHV1-free. We do not expect misclassification in the control farms. The tests were highly specific and sensitive (Kramps et al., 1994) and the tests are repeated on bulk-milk samples every month. Case farms with two or more seronegative bulk-milk samples are also not expected to be misclassified. Two case farms became seropositive 49 and 56 days after certification and might have been misclassified as outbreak farms. Excluding these two farms from the analysis did not influence the results.

Cases and controls came from the same population of certified BHV1-free Dutch dairy farms. The fact that all controls and two-third of the cases were located in the northern part of the Netherlands might have some effect on the estimates. The population of certified BHV1-free dairy farms in different locations were not expected to differ in their management with respect to introduction of diseases. However, the cases and controls were different in herd size and milk production, which might be a form of selection bias. Controls were larger farms with a higher production, and larger farms have more contacts, e.g. veterinarians come more often. The prevalence of BHV1 in the northern part is not different from the average prevalence in the Netherlands (Van Wuijckhuise et al., 1993). However, the percentage of certified BHV1-free farm is slightly higher in the northern provinces (AHS), which partly explains the higher number of cases in this part of the Netherlands. Another reason might be that the AHS did not visit all cases, and that the AHS in the northern part of the Netherlands was more concise in visiting all BHV1 outbreak farms than the AHS in the middle and southern part of the Netherlands. The cases and controls were obtained from the same population; the controls were at risk for introduction of BHV1 as much as the cases. When controls were more at risk due to their larger herd size then the estimates might be underestimated. We expect no effect of the BHV1 prevalence or the percentage of certified BHV1-free farms on the estimates.

The representativeness of the controls for the whole population of certified BHV1-free dairy farms might be influenced by their participation in a study. The controls might have adopted a more closed farming system than the other BHV1-free Dutch dairy farms, which will result in an overestimation of the ORs.

Recall bias of the controls will be negligible, because they registered data and were visited frequently. However, recall bias might exist in the cases, which were visited only once after a BHV1 introduction. The cases might have forgotten risk factors (underestimation of ORs) or might have exaggerated potential risk factors (overestimation of ORs). This nondifferential misclassification will have a two-sided effect so that the estimates are expected to go towards zero.

6.4.4 Data analysis

Fisher's exact test was used since the number in some cells of the two-by-two tables were sparse (smaller than 5) and therefore the normality assumption of the χ^2 analysis was violated (Agresti, 1992). The LogXact software performs conditional exact inference on the parameters of the logistic regression model (Mehta and Patel, 1993). For small data sets, and for data in which both small and large frequencies are expected in the contingency tables, the asymptotic methods are unreliable (Agresti, 1992). Our data set clearly resembled such a data set, because the risk factors were rare events. The BHV1-free farms were closed farms on which little direct animal contacts occurred. An exact modelling approach was therefore most suitable for the data. The unbalanced data made it necessary to select one period of observation of the controls instead of using the data from all three periods. The stratified random selection of the controls assured an unbiased comparison over the different time periods, which was supported by the fact that the model was most significant in the stratified analysis.

The major drawback of using exact methods is the conservatism of the tests (Agresti, 1992). The exact test that was used in the univariable analysis is very conservative, but it limits the type 1 error rate considerably. Asymptotic theory does not provide this assurance (Mehta and Patel, 1993). The mid-P-value, first proposed by Lancaster (1961), is favoured by many statisticians as a way to overcome the conservatism of a discreet test without compromising on the type 1 error (Mehta and Patel, 1993). In this study we reported the mid P-value as well as the asymptotic P-value for the stratified multivariable analysis. These P-values differ most for the variable with low numbers i.e. milking cows breached or escaped, meaning that the distribution of the risk factor was very unbalanced in the two-by-two table (Mehta and Patel, 1993). This supports our choice for the exact tests instead of chi-square distributions.

Survival analysis was considered for the analysis of the data, since the time the farms were BHV1-free (survival time) was known of both cases and controls. However, to be able to use survival analysis the survival time of the controls should be representative for the survival time of all BHV1-free farms in the total population. The controls were not a random sample from the population and the survival time of the total population was not known. Survival analysis could therefore not be used, but would have been a more powerful method in which more information can be incorporated in the analysis (i.e. survival time instead of binary outcome). The risk estimates would be more like relative risks and the survival analysis might have resulted in a larger number and more significant risk factors (Van Schaik et al., 1999).

6.4.5 Concluding remarks

The rate of introduction of BHV1 at BHV1-free dairy farms was fairly low, and the BHV1-free farms already had a relatively closed farming system. However, BHV1 was suntil introduced in some of these farms. The present study showed that direct animal contacts and professional visitors were the most important risk factors for introduction of BHV1, which was in agreement with previous studies of Van Schaik et al. (1998; 2000). Data on risk factors were very detailed, especially data of the controls, but could not be analysed due to a lack of power in the study. However, the management quality was expected to be important to prevent introduction of BHV1. The study showed that although some farms had direct animal contacts, such as purchased cattle or over the fence contacts with other cattle, this does not necessarily mean that such a farm will have introduction of BHV1. The risk of introduction will depend on purchased BHV1-free cattle suntil being free when introduced at the farm or the BHV1 status of neighbouring cattle with which cattle comes in contact over the fence or when escaped. A farmer should be familiar with such important information and adapt his/her management accordingly to prevent introduction of BHV1. A farmer should minimise the risk of cattle that breach or escape and of professional visitors. The management measures to reduce the risk of these factors will mostly cost less than introduction of BHV1 or other infectious diseases into the farm (Van Schaik et al., 2000).

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References

Agresti, A., 1992. A survey of exact inferences for contingency tables. *Statistical Science* 7, 1: 131-177

Hosmer, D.W., and Lemeshow, S. (Eds), 1989. Applied logistic regression. John Wiley and Sons, Inc., New York, 307 pp.

Kramps, J.A., Magdalena, J., Quak, J., Weerdmeester, K., Kaashoek, M.J., Maris-Veldhuis, M.A., Rijsewijk, F.A.M., Keil, G., Van Oirschot, J.T., 1994. A simple, specific and highly sensitive blocking enzyme-linked immunosorbant assay for detection of antibodies to bovine herpesvirus-1. *Journal of Clinical Microbiology* 32: 2175-2181.

Lancaster, H.O., 1961. Significance tests in discreet distributions. *Journal of the American Statistical Association* 56: 223-234.

Nielen, M., Jalvingh, A.W., Horst, H.S., Dijkhuizen, A.A., Maurice, H., Schut, B.H., Van Wuijckhuise, L.A. and De Jong, M.F., 1996. Quantification of contacts between Dutch farms to assess the potential risk of foot-and-mouth disease spread. *Preventive Veterinary Medicine* 28, 3: 143-158.

Nylin, B., Madsen, K.G. and Ronsholt, L., 1998. Reintroduction of BHV 1 into Danish cattle herds during the period 1991-1995: A review of the investigations in the infected herds. *Acta Veterinaria Scandinavia* 39, 4: 401-413.

Mars, M.H., Bruschke, C.J.M. and Van Oirschot, J.T., 1999. Airborne transmission of BHV1, BRSV, and BVDV among cattle is possible under experimental conditions. *Veterinary Microbiology* 66: 197-207.

Mehta, C. and Patel, N., 1993. LogXact user manual. CYTEL Software Corporation. Cambridge, MA.

Stärk, K.D.C., 1999. The role of infectious aerosols in disease transmission in pigs. *The Veterinary Journal* 158: 164-181.

Van Schaik, G., Dijkhuizen, A.A., Huirne, R.B.M., Schukken, Y.H., Nielen, M. and Hage, J.J., 1998a. Risk factors for existence of bovine herpesvirus 1 antibodies on nonvaccinating Dutch dairy farms. *Preventive Veterinary Medicine* 34: 125-136.

Van Schaik, G., Dijkhuizen, A.A., Huirne, R.B.M. and Benedictus, G., 1998b. Adaptive Conjoint Analysis to determine the perceived risk factor of farmers, veterinarians and AI technicians for introduction of BHV1 to dairy farms. *Preventive Veterinary Medicine* 36: 101-112.

Van Schaik, G., Schukken, Y.H., Nielen, M., Dijkhuizen, A.A., Huirne, R.B.M., 1999. Application of survival analysis to identify management factors related to the rate of BHV1 seroconversions in a retrospective study of Dutch dairy farms. *Livestock Production Science* 60: 371–382.

Van Schaik, G., Shoukri, M., Martin, S.W., Schukken, Y.H., Nielen, M. and Dijkhuizen, A.A., 1999. Modeling the effect of an outbreak of BHV1 on herd-level milk production on Dutch dairy farms. *Journal of Dairy Science* 82: 944-952.

Van Schaik, G., Schukken, Y.H., Dijkhuizen, A.A., Barkema, H.W. and Benedictus, G., 2000. The incidence of introduction of infectious diseases at Dutch SPF dairy farms: risk factors and economic consequences. Submitted.

Van Wuijckhuise, L., Bosch, J., Franken, P., Hage, J.J., Verhoeff, J. and Zimmer, G., 1993. The prevalence of Infectious Bovine Rhinotracheitis (IBR) in the Netherlands. In: Elbers, A.R.W. (ed), *Proceedings 6th meeting of the Dutch Society for Veterinary Epidemiol. Economics.* Boxtel. p 7-16.

Vonk Noordegraaf, A., Buijtels, J.A.A.M., Dijkhuizen, A.A., Franken, J.A., Stegeman, J. and Verhoeff, J., 1998. An epidemiological and economic simulation model to evaluate the spread and control of infectious bovine rhinotracheitis in the Netherlands. *Preventive Veterinary Medicine* 36: 219-238.

Chapter 7

Modeling the effect of an outbreak of Bovine Herpesvirus type 1 on herd level milk production of Dutch dairy farms

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Abstract

One of the impacts of disease is its effect on milk production. In order to estimate these effects we used milk production records. Because milk production is measured at regular intervals, the data consist of repeated measures on the herd and cow level. In the present study the effect of an outbreak of BHV1 on herd level milk production of certified BHV1 free dairy farms was modeled. The objective was to study several linear models to quantify the effects of a BHV1 outbreak on milk production accounting for the repeated measures, and incorporating our assumptions about the most likely duration of effects of this virus.
A marginal model, a subject specific random effect model, and a transition model were developed. The effect of a BHV1 outbreak was statistically significant in the random effect model, and this model fitted the investigated farms best. However, a transition model might be a better model for generalizing the results to the whole population of Dutch dairy farms.
The effect of a BHV1 outbreak on milk production derived from the random effect model amounted, on average, to a loss of 0.92 kg of milk per cow per day during a period of nine weeks. The milk production loss varied from almost none to 2 kg of milk per cow per day. This resulted in an average loss of Dfl 372 with a lower and upper confidence limit of respectively Dfl 12 and Dfl 730 per BHV1 outbreak.

Abbreviation key: AIC = akaike's information criteria, **BHV1** = bovine herpesvirus type 1, **CC** = concordance correlation, **CR_TDM** = cubic root of test day milk production, **TDM** = test day milk production.

7.1 Introduction

Several studies have been conducted to find satisfactory models to predict the effect of disease (or other event) on milk production. In the present study the effect of an outbreak of Bovine Herpesvirus type 1 (**BHV1**) on herd level milk production was modeled. BHV1 causes the disease called infectious bovine rhinotracheitis as well as infectious pustular vulvovaginitis. In the near future, stricter requirements are expected in the European Union (and some other countries outside the European Union) regarding the health status of exported breeding cows and material. Therefore, there is a need to eradicate BHV1 in exporting countries such as the Netherlands (Vonk Nooredegraaf et al., 1998). In May 1998 a compulsary eradication program for BHV1 started in the Netherlands. Approximately 30% of the dairy farms already became certified BHV1-free in 1998. The economic consequences of a BHV1 outbreak on these farms is of great importance for the social acceptance and success of the eradication program.

BHV1 can spread easily within farms between cows (Ackermann et al., 1990; Wentink et al., 1993; Hage, 1997). Although the mammary system is not the primary organ affected, the nature of the disease suggests that there could be milk production losses associated with infection. The objective of this study was to find the most appropriate model to estimate the effects of a BHV1 outbreak on herd level production and to quantify this effect.

7.2 Materials and methods

7.2.1 Data

Data were available from dairy farms in the Netherlands that were certified BHV1-free after individual blood sampling but experienced a BHV1 outbreak in 1997, as well as data from certified BHV1-free farms without BHV1 outbreak. In the Netherlands, the status of BHV1-certified farms is monitored by monthly bulk milk samples taken by the Animal Health Service (GD, Drachten, The Netherlands). The date when the BHV1-free status was obtained was known as well as the date when a BHV1-positive bulk milk sample was found. Monthly measures of farm level milk production were obtained from the Dutch Cattle Syndicate (NRS, Arnhem, The Netherlands). Initially, we used data from 62 farms, 45 with and 17 without an outbreak extended from January 1992 to December 1997, and data from 78 farms without a BHV1 outbreak ranged from June 1996 to November 1997.

7.2.2 Dependent variables

The total test day milk production at the farm level (**TDM**) was not normally distributed but exhibited some skewness. To bring this distribution to symmetry, the cubic root of the TDM (**CR_TDM**) was calculated and used as the dependent variable in the models (Sakia, 1992).

7.2.3 Independent variables

A dummy variable (BHV1POS) was created to define the period in which the production of a farm was affected by the BHV1 outbreak. The definitions for BHV1POS were based on a previously described BHV1 outbreak on a typical farm (Hage et al., 1996). After first introduction of the virus there is an incubation period of approximately 5 d until clinical signs appear. Approximately 10 d after infection antibodies can be detected in the blood (Kaashoek, 1995). At the farm level, bulk milk antibodies can be found 10 d after first introduction of the virus, also. However, this is dependent on the percentage of infected cows; when less than 15% of the cows in the milking herd are infected, the bulk milk can still test negative.

Following introduction of the virus to a herd, there is a period of about six weeks in which, in most cases, the virus infects all dairy cows (Hage et al., 1996). The reproduction ratio (R_o) is defined as the average number of secondary cases generated by one primary case in a wholly susceptible population of defined density (Becker, 1989). Based on an R_o of approximately 7, it can be calculated that in 15% of the BHV1 outbreaks a minor outbreak will occur in which not all cows in the herd will become infected (Hage et al., 1996). Nonetheless, we assumed all outbreaks were major and that the influence of the infection on farm level milk production is expected from two weeks after introduction of the virus to approximately six weeks after introduction (Hage et al., 1998). Hence, given monthly testing, the moment a BHV1-positive bulk milk sample was found can be two to six weeks after BHV1 was introduced on the farm and the BHV1 outbreak might still affect milk production up to three weeks after the first BHV1-positive sample was found. All farms that did not have a certificate at least six weeks before the BHV1-positive sample was found, were excluded from the analysis as it is uncertain whether these farms were truly BHV1-free in the period before the BHV1 outbreak. Therefore, a test day milk production measure was defined as being affected by a BHV1 outbreak when it occurred 6 weeks or less before the date that a BHV1-positive milk sample was collected on the farm and three weeks or less after a BHV1-positive milk sample was found. Therefore, all losses due to the BHV1 outbreak were calculated over a nine weeks period. Figure 1 shows graphically how the dummy variable BHV1POS was defined.

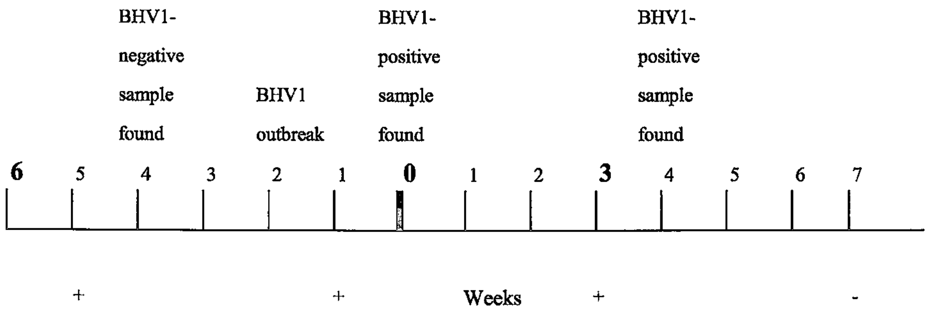

Figure 1. Time frame of a bovine herpesvirus type 1 (BHV1) outbreak. Milk test days were conducted during week -5, -1, 3, and 7. + = milk production affected by a BHV1 outbreak; - = milk production not affected by a BHV1 outbreak.

In the Netherlands, milk production is influenced by season. Dairy cows usually go outside for grazing from May to November and are kept in the barn during winter. In February-March, farm level milk production increases till June-July when it decreases. In late summer or autumn (August – October) a higher percentage of cows calve in the Netherlands because of higher milk prices in winter resulting again in an increasing farm level milk production (Centraal Bureau Statistiek, 1998). The seasonal influence in these time-series data was obvious on visual analysis and was modeled with a combination of cosine-sine components (Chatfield, 1984).

The models used in the analyses are represented by the formulas 1, 2, and 3. Formula 1 represents the marginal model with only fixed effects. Model 2 is the model with fixed as well as random herd-year effects (PROC MIXED, random FARM YEAR FARM × YEAR). The basic idea underlying the random effect model is that there is natural heterogeneity across herds in their regression coefficients and that this heterogeneity can be represented by a probability distribution (Diggle, 1990). Formula 3 is a transition model with a correlated residual error structure (PROC MIXED, repeated MOYRTD / type = AR(1) subject = FARM). With formula 3 we model the conditional distribution of CR_TDM given the prediction error of the preceding CR_TDM and the explanatory variables (Diggle, 1990). Using SAS statements, "random" generates a farm specific effect; where using the "repeated" statements generates population average effects. For both Model 2 and 3 several covariance structures were tested (e.g. variance components (VC), first-order autoregressive structure (AR(1)), and compound symmetry (CS)).

Model 1:

$$CR\_TDM = a_1 + b_1 \times BHV1POS + c_1 \times COS(2\pi t / f) + d_1 \times SIN(2\pi t / f) + f_1 \times \#TESTCOW + g_1 \times FARM + h_1 \times YEAR + E \quad (1)$$

$E \sim N(0, \sigma^2)$

Model 2:

$$CR\_TDM = a_2 + b_2 \times BHV1POS + c_2 \times COS(2\pi t / f) + d_2 \times SIN(2\pi t / f) + f_2 \times \#TESTCOW + \delta \times FARM \times YEAR + E \quad (2)$$

$\delta \sim N(0, \sigma_{FY}^2)$

$E \sim N(0, \sigma_e^2)$

Model 3:

$$CR\_TDM = a_3 + b_3 \times BHV1POS + c_3 \times COS(2\pi t / f) + d_3 \times SIN(2\pi t / f) + f_3 \times \#TESTCOW + E \quad (3)$$

E is split into a correlated part MOYRTD within FARM and a random – normal part $\sim N(0, \sigma_e^2)$

where

CR_TDM	=	cubic root of the test day milk production on farm level,
$a_{1,2,3}$	=	intercept,
b_1	=	the average effect of a BHV1 outbreak on the cubic root of TDM over the sub-population of BHV1-infected herds,
b_2	=	the effect of a BHV1 outbreak on an individual farm's cubic root of TDM,
b_3	=	the average effect of a BHV1 outbreak on the cubic root of TDM among the population of herds that were previously BHV1-free,
$c_{1,2,3}$,$d_{1,2,3}$	=	amplitude of respectively the cosine and sine function at a certain phase,
$f_{1,2,3}$,g_1,h_1	=	regression coefficients,
t	=	month (1 to 12),
f	=	number of cycles per unit of time (i.e. 12),
BHV1POS	=	milk production affected (= 1) or not affected (= 0) by a BHV1 outbreak,
#TESTCOW	=	the number of cows tested for the TDM measures,
FARM	=	unique herd identification number (as fixed or random effect),
YEAR	=	year (1992 – 1997) of test day milk production (as fixed or random effect),
MOYRTD	=	month and year of the test day, 1 = Jan.'92, 2 = Feb.'92, to 72 = Dec.'97 (as repeated statement with a first order autoregressive correlation structure in SAS), and
E	=	random error ~ $N(0, \sigma^2)$.

7.2.4 *Selection and comparison of the models*

The models were compared using the Akaike's information criterion (**AIC**) (Akaike, 1974) to select the best model. The AIC is computed as AIC = $l(\theta) - q$, where $l(\theta)$ is the maximized log likelihood, and q is the number of parameters. It can be used to compare models with the same fixed effects but different variance structures; the closer the AIC is to zero, the better the model.

The goodness of fit of the model was assessed using the concordance correlation coefficient (**CC**) and visual analysis of the graphs of observed and predicted values. The CC was first constructed to validate the reproducibility of a measuring device or a clinical test for interval scale measurements. However, this index can be extended to effectively measure the goodness of fit of a model. High values of the CC (above 80%) between the observed data and the predicted data based on our model, would indicate that the model has high reproducibility (Lin, 1989). The formula representing the CC is:

$$CC = \frac{2 r_p S_o S_p}{S_o^{\,2} + S_p^{\,2} + (\mu_o - \mu_p)}$$

where

r_p	=	Pearson's correlation coefficient,
S_o	=	observed standard deviation,
S_p	=	predicted standard deviation,
μ_o	=	observed mean, and
μ_p	=	predicted mean.

7.2.5 Data analysis

The procedure MIXED of SAS 6.12 for Windows was used to model the data (SAS/STAT® User's Guide, 1989). As part of this, the cubic root of TDM (CR_TDM) was tested for normality with the Kolmogorov test. The interaction between BHV1POS and #TESTCOW was tested for significance. In addition, outliers in the model were investigated and residuals were plotted and tested for correlation's and autocorrelation. Finally, the predictive value of the model for the milk production on farms affected by a BHV1 outbreak was examined. With the estimates of the model the effect of a BHV1 outbreak on herd level milk production was quantified. The 95% confidence interval (95% CI) of the estimated milk production loss was calculated under the normal assumption. The economic losses due to the effect of the BHV1 outbreak on milk production were calculated for the average farm in the study (43 cows in milk). The economic value of a kilogram of milk was assumed to amount Dfl 0.15 (Dfl 1 = US$0.50 = 0.45 ECU, June 1998) (Dijkhuizen and Morris, 1997).

7.3 Results

7.3.1 Descriptive analysis

Six farms with a BHV1 outbreak were excluded from the analyses because they obtained their BHV1-free certificate less than 6 weeks before the outbreak. One farm without a BHV1 outbreak was excluded from the analyses because it had at maximum 13 lactating cows and therefore was an outlier with regards to herd size. The analyses were done with 133 farms, 39 with a BHV1 outbreak and 94 without. The CR_TDM had a normal distribution according to the Kolmogorov test statistic. Fifty-four of the CR_TDM on the 39 farms were defined as affected by a BHV1 outbreak. Some descriptive results of the continuous variables are shown in Table 1.

Table 1: Descriptive results of test day milk production (TDM), the cubic root of TDM (CR_TDM), and the number of cows tested (#TESTCOW) (n = 4409).

Variables	Mean	Median	Min	Max	Skewness	Kurtosis	Kolmogorov test statistic
TDM, kg	1087.3	993.0	120.0	3972.0	1.25	2.37	0.088
CR_TDM, kg	10.0	10.0	4.9	15.8	0.12	0.20	0.026
#TESTCOW	43.5	40.0	6.0	141.0	1.31	2.62	0.098

7.3.2 Seasonality in the data

Figure 2 shows the seasonal fluctuation of farm level milk production of the investigated Dutch dairy farms. The pattern of the milk production is different in 1996 and 1997, which is most likely because of the extra data from the control group (n = 94) of nonoutbreak certified BHV1-free farms with data from June 1996 till November 1997.

7.3.3 Model results

Table 2 shows the results of the marginal model (1). Table 3 shows the results of the random effects model (2). In Table 4 the results of the transition model (3) is summarized. The interaction between BHV1POS and #TESTCOW was not significant in any of the models.

Table 2: Multivariate linear regression on the cubic root of test day milk production (Model 1).

Solution of fixed effects	Estimate	SE	df	Type III F	P > F
Intercept	6.08	0.177	1	34.41	0.0001
BHV1POS[a] = 0	0.00	...	...	...	...
BHV1POS[a] = 1	-0.13	0.070	1	3.40	0.0651
COS1[b]	-0.17	0.011	1	255.95	0.0001
SIN1[c]	0.08	0.011	1	60.34	0.0001
#TESTCOW[d]	0.07	0.001	1	2620.02	0.0001
Farm	...	...	138	31.91	0.0001
1992	-0.27	0.029	1	-9.11	0.0001
1993	-0.19	0.029	1	-6.41	0.0001
1994	-0.18	0.029	1	-6.20	0.0001
1995	-0.11	0.029	1	-3.59	0.0001
1996	-0.05	0.022	1	-2.28	0.0230
1997	0.00	...	...	...	...

[a] BHV1POS = milk production affected (= 1) or not affected (= 0) by a BHV1 outbreak,
[b] COS1 = cosine function,
[c] SIN1 = sine function,
[d] #TESTCOW = the number of cows tested for the milk production on the test day.

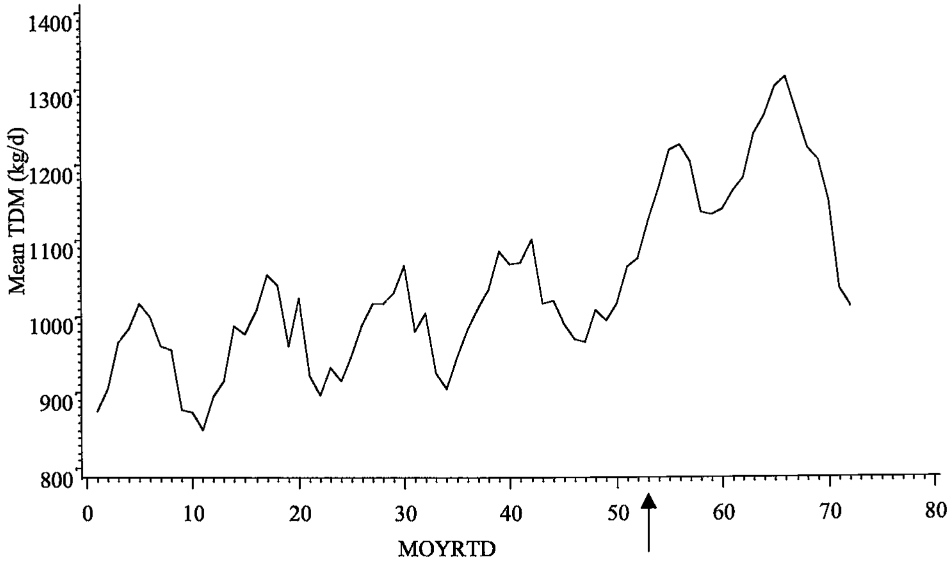

Figure 2. Mean observed daily herd level milk production (TDM) by month of test day. The number of farms increased from 39 to 133 in month and year of test day (MOYRTD) 53.

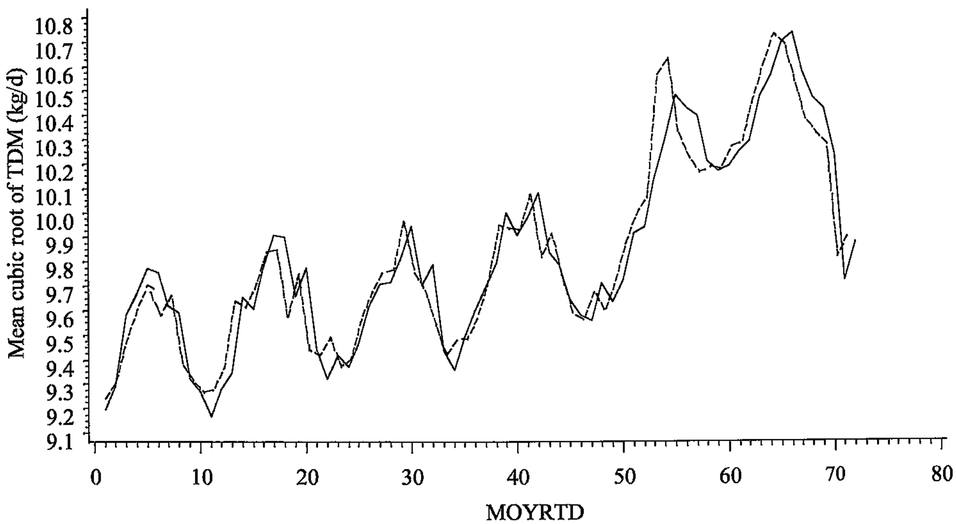

Figure 3. The observed (—) and predicted (---) cubic root of test day milk production (TDM) by month and year of test day (MOYRTD) of Model 1.

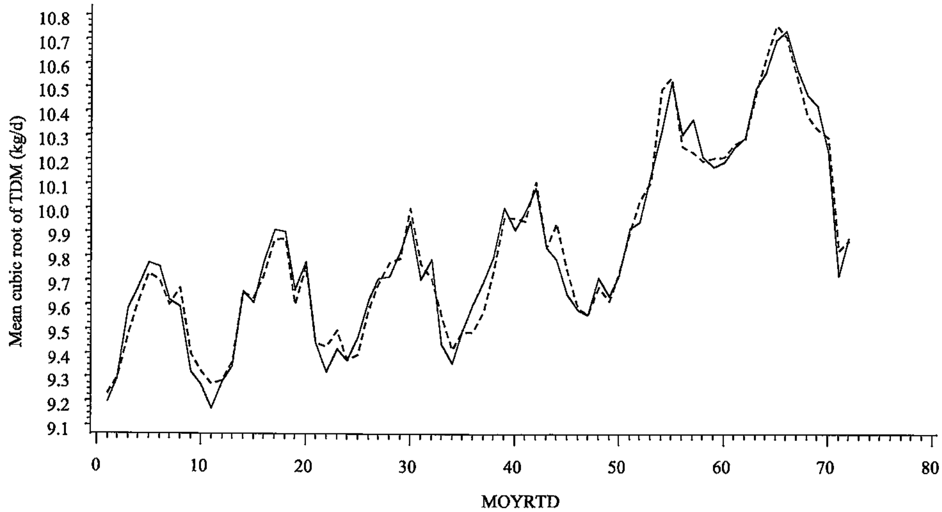

Figure 4. The observed (—) and predicted (---) cubic root of test day milk production (TDM) by month and year of test day (MOYRTD) of Model 2.

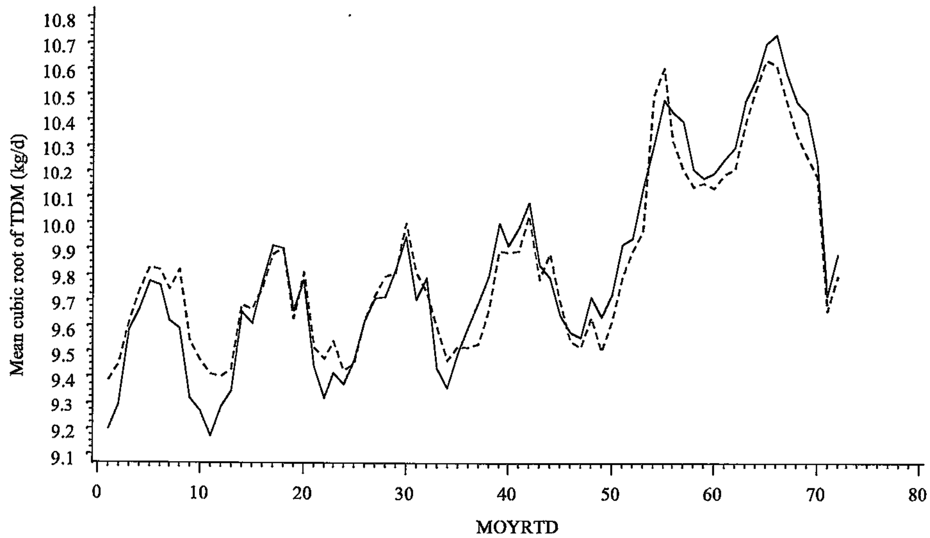

Figure 5. The observed (—) and predicted (----) cubic root of test day milk production (TDM) by month and year of test day (MOYRTD) of Model 3.

In Model 1 all variables, except BHV1POS, were significantly associated with CR_TDM. In a second fit, the year of the test day (YEAR) was included in the model as a continuos linear variable, and this improved the fit of this model but did not change the estimates of the other variables. Figure 3 shows the graphs of the observed and predicted CR_TDM.

The predicted CR_TDM appeared to fit the observed values reasonably well. In Table 3 the results of Model 2 with random effects and the VC covariance structure are shown. In Model 2 all variables were significantly associated with CR_TDM.

Table 3: Estimates of Model 2 with random farm and year effects.

Solution of fixed effects	Estimate	SE	t	P > |t|
Intercept	6.84	0.106	64.63	0.0001
BHV1POS[a] = 0	0.00	...	...	...
BHV1POS[a] = 1	-0.14	0.070	1.94	0.0522
COS1[b]	-0.17	0.011	-15.98	0.0001
SIN1[c]	0.08	0.011	7.65	0.0001
#TESTCOW[d]	0.07	0.001	61.69	0.0001
REML of random effects				
Farm	0.204			
Year	0.011			
Farm × Year	0.033			
Residual	0.215			

[a] BHV1POS = milk production affected (= 1) or not affected (= 0) by a BHV1 outbreak,

[b] COS1 = cosine function,

[c] SIN1 = sine function,

[d] #TESTCOW = the number of cows tested for the milk production on the test day.

Figure 4 shows the graph of the observed and predicted CR_TDM per test month for Model 2. The predicted values are very similar to the observed values, which is confirmed by the high CC of 0.97.

Table 4 shows the results of the transition model (3) with the correlated residual errors. In Model 3 all variables, except BHV1POS, were significantly associated with CR_TDM.

Figure 5 shows that the goodness of fit of Model 3 was not as good as that of the previous models 1 and 2. Overall, the predicted values were quite different from the observed values. A transition model with a first-order autoregressive structure (AR(1)) gave the best results (AIC closest to zero).

Table 4: Estimates of the transition Model 3 with a correlated residual error structure.

Solution of fixed effects	Estimate	SE	t	P > |t|
Intercept	6.60	0.35	19.00	0.0001
BHV1POS[a] = 0	0.00	...	...	...
BHV1POS[a] = 1	-0.08	0.060	1.25	0.2100
COS1[b]	-0.18	0.015	-11.72	0.0001
SIN1[c]	0.07	0.016	4.68	0.0001
#TESTCOW[d]	0.06	0.002	35.87	0.0001
Farm	...	...	5.69	0.0001

[a] BHV1POS = milk production affected (= 1) or not affected (= 0) by a BHV1 outbreak,
[b] COS1 = cosine function,
[c] SIN1 = sine function,
[d] #TESTCOW = the number of cows tested for the milk production on the test day.

Table 5 gives an overview of the model fitting information of the three tested models. The transition model (model with the correlated residual error structure) had a higher residual and a lower CC. The random effects model (2) had the lowest residual and the highest CC and appeared to be the best model according to the fitting information. All variables in Model 2 were significant. Model 2 with the VC covariance structure was the best model according to the AIC. Other covariance structures resulted in larger AIC. Having a BHV1 outbreak (BHV1POS = 1) was negatively related to CR_TDM with a coefficient of -0.14.

Table 5: Fitting information of the three tested models.

Model[a]	Residual	Akaike's information criteria	-2 Residual Log Likelihood	Concordance correlation
1	0.238	-3236.24	6470.48	0.96
3	0.344	-2278.32	4552.64	0.95
2	0.215	-3263.67	6527.35	0.97

[a] Model 1 was a marginal model, Model 3 had a correlated error structure, and Model 2 had random farm and year effects.

The residuals of Model 2 were checked for correlation and autocorrelation with herd and year. The correlation was not statistically significant. A residual plot of Model 2 is shown in Figure 6. Note that the residuals are symmetrical around zero and this implies that Model 2 has captured most of the variability. In the residuals of Model 2 there was an autocorrelation of 0.43. However, Model 2 with the VC covariance structure had an AIC closest to zero.

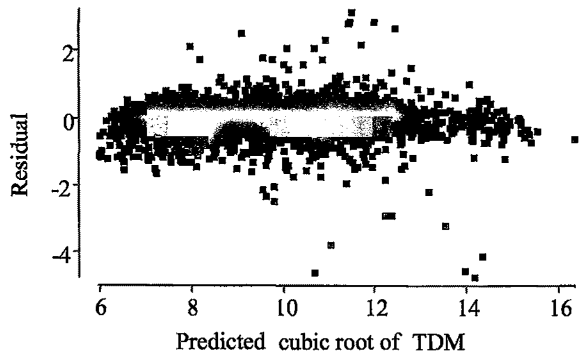

Figure 6. A plot of the residual by the predicted cubic root of test day milk production (TDM) of Model 2 (Table 3).

Twenty-three cases had a residual larger than two and were investigated. Twenty-two of the outliers occurred in June to September 1996. In June and July the outliers had a lower than average production and in August and September a higher than average production.

The between-farm variability can be calculated as the covariance estimate of FARM divided by the overall covariance and equals 0.44. The between year variability was 0.03 and the between farm between year variability was 0.08.

Model 2 was tested for its predictive value for the milk production during a BHV1 outbreak by comparing the observed and the predicted values of the CR_TDM of the 54 test results during the outbreak. The results are shown in Table 6. The residual (observed minus predicted) was equal to zero implying that there was no significant difference between the mean of the observed and predicted values of the BHV1 affected CR_TDM. Hence, the estimate was unbiased.

Table 6: Test of the random effect Model 2 for its predictive value for cubic root of test day milk production (CR_TDM) after a bovine herpesvirus type 1 outbreak (n = 54).

	Mean	SD	Skewness	Kurtosis
Observed CR_TDM	10.01	1.73	-0.45	-0.36
Predicted CR_TDM	10.01	1.63	-0.36	-0.59
Residual	0.00	0.38	-1.34	2.85

The milk production loss was calculated for the average number of tested cows (43) in the herds under study based on the estimates of Model 2. The milk production loss was highest (40.9 kg) in May and lowest in November (37.8), and on average was 39.4 kg per farm per test day. The effect of a BHV1 outbreak on an average farm of 43 cows was calculated for a period of nine weeks. This would result in a total loss in milk production of 39.4 × 63 d = 2482 kg of milk, equal to 39.4 / 43 = 0.92 kg per cow per day. In severe cases this might become on average 77.3 × 63 d = 4870 kg of milk or in less severe cases this might only be 1.3 × 63 = 82 kg of milk. In this study it was assumed that the economic value of a kilogram of milk amounted Dfl 0.15. On average a farm experienced a loss of 2482 kg × Dfl 0.15 = Dfl 372 with a 95% CI of Dfl 12 to Dfl 730 per BHV1 outbreak. The average net return to labor and management per year on a Dutch dairy farms with 43 cows in milk was Dfl 1500 × 43 = Dfl 64500. The average loss due to a BHV1 outbreak accounted for less than 1% of the net return.

7.4 Discussion

The present models have a clear resemblance to the unbalanced repeated measures or longitudinal studies models developed by Laird and Ware (Laird and Ware, 1982). Such models were later extended and formalized by Jennrich and Schluchter (1986) to accommodate a wide range of correlation structures. We decided to use PROC MIXED in SAS, rather than the traditional MANOVA of repeated measures experiment that depends on the decomposition of total sum of squares. The reason is that PROC MIXED utilizes a likelihood-based approach, which is more efficient (results in smaller standard errors), and is well suited to the analysis of data with a hierarchical structure (Diggle et al., 1994).

The variables included in the models describe the seasonal fluctuation of the milk production (COS and SIN). The #TESTCOW was included in the model to describe the number of cows on which the TDM measure was based. Within a farm, the number of cows measured might vary from month to month because of the number of cows that were dried off or calved. The TDM was a measure repeated on the farm for several years and several times per year. The number of measures per farm differed and the data were unbalanced; however, PROC MIXED can deal with unbalanced designs. Other time series procedures would need balanced data or were unable to include terms describing the seasonal fluctuations in the dependent variable.

The marginal model (1) already fitted the data well. However, Model 1 did not include possible correlation structures in the data. Based on the structure of the data (i.e. repeated measures within a farm and within a year) the use of the transition model (3) seemed more appropriate. However, the random effects model (2) was more precise in estimating the effect of a BHV1 outbreak for a specific farm. The basic idea underlying the random effect model (Diggle et al., 1994) might be true for the farms in the study. The farms have a natural heterogeneity (because of e.g. management) but this heterogeneity can be represented by a probability distribution. The regression coefficient of the BHV1 outbreak of Model 2 represents the effect of that outbreak on the individual farm. The results show that Model 2 better estimated the milk production according to the higher concordance correlation (CC) and smaller residuals compared with Model 3. Also, in the graph of Model 2 (fig. 3) the predicted values seemed to be closer to the observed values. The marginal Model 1 (Table 2) had a (slightly) lower CC than the random effects model (2), respectively 0.96 and 0.97 (Table 5). The AIC of Model 1 in Table 2 cannot be compared with the Models 2 and 3, because the fixed effects differ between the models. As noted earlier, the transition model (3) (with a correlated error structure) describes the population average. All of the variance of this population average model was included in the residual. However, in Model 2 (with random effects), which is subject (farm) specific, the total variance is divided over farm, year and residual. This is shown by the lower residual of Model 2 compared with Model 3 (Table 5).

The decision whether to use a subject specific or a population average model to analyze data should also depend on the type of prediction one wishes to perform. A subject specific model means that the results are conditional on the knowledge of the individual farm (a given farm). In contrast, Model 3 (with a correlated error structure) describes the population average and the predictive value of this model is for an average BHV1 outbreak among the population of herds which were previously BHV1-free. The results of Model 3 can be more easily generalized for the whole population of BHV1-free Dutch dairy farms. The transition model (3) estimates the average BHV1 outbreak effect, albeit with less accuracy than the subject specific model.

In this study our objective was to quantify the effect of a BHV1 outbreak on milk production. The random effects model (2) gave the most precise estimates. There was still autocorrelation of 0.43 present in the residuals. This moderate autocorrelation will not affect the point estimate, but might increase the standard error of the estimate (Diggle, 1990). However, Model 2 with the VC covariance structure had an AIC closest to zero. The standard error in this model is therefore corrected most for autocorrelation.

From the variance components estimates in Table 3 it could be calculated that most of the random effect is covered by the between-farm variability of 0.44 (FARM as random effect). The between-year and between-farm-between-year variability were much smaller, respectively 0.03 and 0.08.

As an attempt at validation, the goodness of fit of the models was specifically tested for the months in which an outbreak occurred on a farm. In the final model (random effects model (2)) 54 test days were defined as being affected by a BHV1 outbreak. The results in Table 6 show no difference between the observed and predicted outcomes of Model 2 suggesting that the predictive value of the model for the months in which a BHV1 outbreak occurred was good.

Despite the presence of some outliers, they were not excluded from the final model. Doing so would not change the estimates but only slightly decrease the standard errors of the model. The outliers were most likely caused by extreme weather conditions during the summer of

1996. June and July were extremely dry months causing a decrease in grass quality and milk production. In August, rain considerably increased grass quality and milk production.
The results of the study show a negative effect of a BHV1 outbreak on the milk production on Dutch dairy farms. The BHV1 outbreak caused an average milk production loss of 39 kg per day for a herd of 43 milking cows. This was a higher figure than the 9,5 kg per cow found by Hage et al. (1998). However, Hage et al. (1998) investigated a subclinical seroconversion of initially seronegative dairy cows on a farm at which 56% of the cows were serologically positive. The standard error of the estimate is quite large indicating that the decrease in milk production will vary greatly between farms. Based on a 95% CI, the average milk production loss on the farm level can become as high as 77 kg and as low as 1.3 kg per farm per day. Kaashoek (1995) found that virus strains differed considerably in the severeness of clinical signs they produced. The variability of the decrease in milk production can also be caused by the type of outbreak (e.g. subclinical or clinical signs) as well as the extent (major or minor) of the outbreak. The farmer might also be able to minimize the effect of a BHV1 outbreak by management. Van Schaik et al. (1998) found that an overcrowded barn seemed to increase the rate of BHV1 reinfections and this might also have an influence on the severity or size of an outbreak. Furthermore, the economic value of a kilogram of milk with average milk solid contents corrected for variable costs varied according to the management of the farmer. Dutch dairy farms produce under a quota system which influences the economic value of a kilogram of milk. In case a farmer can increase milk production enough to fill the quota, the losses are due to inefficient production and the economic value of a kilogram milk is Dfl 0.15. The other scenario is when a farmer cannot compensate the losses due to a BHV1 outbreak (e.g. an outbreak just before the end of the quota-season). The economic value of a kilogram of milk then amounts Dfl 0.55 (Dijkhuizen and Morris, 1997). In the present study it was assumed that the economic value of a kilogram of milk amounted Dfl 0.15. The effect of management on the losses of a disease outbreak on a farm should be further investigated.
Hage et al. (1998) found that the effect of a BHV1 outbreak on milk production on a dairy farm lasted approximately 5 weeks after which all cows had seroconverted. In the present study a wider period of nine weeks was used to base the milk production losses on. False-negative and false-positive milk test days might be included in this period. In our opinion the BHV1 outbreak is often discovered at least 5 or 6 weeks after the actual outbreak which implies that the milk production in the three-week period after an outbreak is discovered might often not be affected anymore by the initial infection. However, when most of the effect of the BHV1 outbreak will be included in the nine weeks period, the losses due to a BHV1 outbreak will be estimated accurately by our models. We assumed that all outbreaks were major (all milking cows infected). However, 15% of the outbreaks might have been minor (Hage et al., 1996), in which case we will underestimate the losses due to a BHV1 outbreak.

Effects of diseases on milk production are commonly hard to prove because of the high variability of milk production caused by external factors (such as weather conditions, feeding regime, et cetera). The present study showed that an appropriate model that fits the data well seemed to correctly identify and predict the relatively small effect of a BHV1 outbreak on milk production.

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References

Ackermann, M., Müller, H.K., Bruckner, L. and Kihm, L., 1990. Eradication of infectious bovine rhinotracheitis in Switzerland: review and prospects. *Veterinary Microbiology* 23:365-370.

Akaike, H., 1974. A new look at the statistical model identification. IEEE Transaction on Automatic Control AC-19:716-723.

Becker, N.G., 1989. Analysis of infectious disease data. Chapman and Hall Ltd., London, United Kingdom.

Centaal Bureau Statistiek. 1998. Maandstatistiek van de Landbouw. CBS, Voorburg, The Netherlands.

Chatfield, C., 1984. The Analysis of Time Series: An Introduction. 3rd ed. Sci. Paperbacks, Chapman and Hall Ltd., London, United Kingdom.

Diggle, P.J., 1990. Implications of autocorrelation for elementary statistical methods. Pages 87-92 in Time Series: A Biostatistical Introduction. Oxford Univ. Press, Inc., New York, NY.

Diggle, P.J., Liang, K.-H. and Zeger, S.L., 1994. Analysis of Longitudinal Data. Oxford Univ. Press Inc., New York, NY.

Dijkhuizen, A.A. and Morris, R., 1997. Animal Health Economics: Principles and Applications. Post Graduate Found. Veterinary Sciience, Sydney, Australia.

Hage, J.J., Schukken, Y.H., Barkema, H.W., Benedictus, G., Rijsewijk, F.A.M. and Wentink, G.H., 1996. Population dynamics of bovine herpesvirus 1 infection in a dairy herd. *Veterinary Microbiology* 53: 169-180.

Hage, J.J., 1997. Epidemiology of bovine herpesvirus 1 infections. Ph.D. Diss., Utrecht Univ., Utrecht, The Netherlands.

Hage, J.J., Schukken, Y.H., Dijkstra, T., Barkema, H.W., Valkenhoed, P.H.R., and Wentink, G.H., 1998. Milk prduction and reproduction during a subclinical bovine herpesvirus 1 infection on a dairy farm. *Preventive Veterinary Medicine* 34: 97-106.

Jennrich, R.I. and Schluchter, M.D., 1986. Unbalanced repeated measures models with structured covariance matrices. *Biometrics* 42: 805-820.

Kaashoek, M.J., 1995. Marker vaccines against bovine herpesvirus 1 infections. Ph.D. Diss., Utrecht Univ., Utrecht, The Netherlands.

Laird, N., and Ware, J.H., 1982. Random effects models for longitudinal data. *Biometrics* 38: 963-974.

Lin, L.I., 1989. A concordance correlation coefficient to evaluate reproducibility. *Biometrics* 45: 255-268.

Sakia, R.M., 1992. The Box-Cox transformation technique: a review. *Statistician* 41: 169-178.

SAS/STAT® User's Guide, Version 6, Vol. 1, 4th Edition. 1989. SAS Inst., Inc., Cary, NC.

Van Schaik, G., Dijkhuizen, A.A., Huirne, R.B.M., Schukken, Y.H., Nielen, M. and Hage, J.J., 1998. Risk factors for existence of bovine herpesvirus 1 antibodies on nonvaccinating Dutch dairy farms. *Preventive Veterinary Medicine* 34: 125-136.

Vonk Noordegraaf, A., Buijtels, J.A.A.M., Dijkhuizen, A.A., Franken, P., Stegeman, J.A. and Verhoeff, J., 1998. An epidemiological and economic simulation model to evaluate the spread and control of infectious bovine rhinotracheitis in the Netherlands. *Preventive Veterinary Medicine* 36: 219-238.

Wentink, G.H., Van Oirschot, J.T. and Verhoeff, J., 1993. Risk of infection with bovine Herpesvirus 1 (BHV1): a review. *Veterinary Quarterly* 15: 30-33.

Chapter 8

Introduction of infectious diseases into Dutch SPF dairy farms: risk factors and economic consequences

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Abstract

To be able to eradicate infectious diseases farms need to be more closed to prevent new introduction of the diseases. The profitability of a more closed system will depend on the costs of the measures and on the potential losses due to introduction of diseases.

Ninety-five SPF dairy farms were selected from a database of BHV1-free farms for a cohort study on the possibilities of a more closed farming system to prevent introduction of Bovine Herpesvirus type 1 (BHV1), Bovine Viral Diarrhoea Virus (BVDV), *Salmonella enterica subsp. enterica serotype Dublin* (*S. dublin*), and *Leptospira interrogans serovar hardjo* (*L. hardjo*).

Although the SPF farms were already mainly closed, the probability of introduction of infectious diseases was high, 14 introductions at 95 farms. The study showed that the "non-outbreak" farms were significantly more closed than the "outbreak" farms. Direct animal contacts with other cattle should be avoided and professional visitors should be convinced of the necessity to put on protective clothing before handling cattle. The economic calculations showed that this will be profitable for an SPF farm. On average, the costs for the management measures were lower than the avoided losses of introduction of infectious diseases.

8.1 Introduction

There is a growing awareness of the need to eradicate infectious diseases. Several countries within the European Union (EU) recently obtained a better health status, implying they can restrict import of cattle and semen from countries with a lower health status. Several countries, especially the Scandinavian countries are already officially free or running eradication programs for Bovine Herpesvirus type 1 (BHV1), Bovine Virus Diarrhea Virus (BVDV), *Salmonella enterica* subsp. *enterica* serotype Dublin (*S. dublin*), and *Leptospira interrogans serovar hardjo* (*L. hardjo*) (Straub, 1991; Aho et al., 1998; Lindberg and Alenius, 1999; Nuotio et al., 1999). the Netherlands is an exporting country and therefore a low health status will cause economic losses at country and farm level. Numerous studies show that the presence of BHV1, BVDV, *L. hardjo*, and *S. dublin*, have considerable economic consequences (Anderson and Blanchard, 1989; Bolin and Alt, 1998; Hage et al., 1998; Houe, 1999). Specific pathogen free herds (SPF) are well known in pig production (Kuiper and Martens, 1994), but little research has been done in dairy cattle (De Verdier Klingenberg et al., 1999). By eradicating one or more infectious diseases a farm becomes specific pathogen free. The benefits of an SPF herd in pigs are better technical results (Kuiper and Martens, 1994) and this may also be expected in dairy herds. However, an SPF herd is susceptible to introduction of infectious diseases and therefore has to adapt its management to prevent economic losses due to introduction.

BHV1 causes infectious bovine rhinotracheitis (IBR) as well as infectious pustular vulvovaginitis (IPV), and was introduced in the Netherlands in the 70s. BHV1 has successfully been eradicated in Denmark, Austria and Switzerland (Straub, 1991). In May 1998 a compulsory eradication program for BHV1 started in the Netherlands (Vonk Noordegraaf et al., 1998). This program requires that farms either vaccinate all cattle twice a year or approve for a certified BHV1-free status. To become a certified BHV1-free herd, cattle has to be sampled individually and all seropositive animals need to be culled shortly after their status is known. The BHV1-free herd status is monitored by monthly bulkmilk samples. Approximately 24% of the Dutch dairy farms was certified BHV1-free in December 1999 (Dutch Animal Health Service (AHS)). An outbreak of BHV1 causes milk production losses at BHV1-free farms and at farms where only part of the cattle is susceptible (Hage et al., 1998;Van Schaik et al., 1999). Other potential losses are abortions, compulsory vaccination of all cattle, and the need to redo the certification program (blood sample all cows and removing seropositive cows).

BVDV is a common virus that causes economic losses worldwide (Houe, 1999). In the Netherlands no vaccination for BVDV is permitted and 70-80% of the dairy cattle have antibodies against the disease (Franken et al., 1986). On a sero-positive farm on average 1- 2 % of the cattle older than one year are virus-carriers (Houe, 1999). Carriers are the main source of infections with BVDV (Houe and Meyling, 1991). At approximately 38% of the Dutch dairy farms BVDV carriers are present (AHS). BVD clearly causes economic losses (Houe et al., 1993), especially when first introduced (Wentink and Dijkhuizen, 1990; Moerman et al., 1994; Stelwagen and Dijkhuizen, 1998; De Verdier Klingenberg et al., 1999; Houe, 1999). Wentink and Dijkhuizen found an average loss of Dfl.1362 per cow, which equaled 10-15% of a farmer's normal income. Furthermore, simulations were carried out to estimate the effects of BVDV infections at the herd level on the longer term (Pasman et al., 1994; Sørensen et al., 1995; Groenendaal, 1998; Houe, 1999). the Netherlands has a voluntary program to eradicate BVDV or certify for BVDV-free status. Testing is based on a PCR on bulk milk to detect adult carriers; youngstock is examined using a PCR on pooled blood samples. If the PCR is positive, individual blood samples are examined using virus isolation. In the next 12 months all calves born are sampled. Carriers need to be removed from the farm within two weeks. The BVDV-free status is monitored by sampling 5 calves every six months. In December 1999, 619 dairy farms in the Netherlands were certified BVDV-free and approximately 700 dairy farms were in the certification process (AHS). In Shetland BVDV

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2 US$ 1 = € 2 = Dfl. 2.15, December 1999.

had already been eradicated successfully and the Scandinavian countries are well on their way towards eradication (Lindberg and Alenius, 1999).

L.hardjo has been associated worldwide with mastitis, sudden drop in milk yield, abortions, suntilbirth and the birth of weak calves. Furthermore, *L. hardjo* is a zoonotic threat (Bolin and Alt, 1998). A monitoring program for *L. hardjo* has existed in the Netherlands for several years and has resulted in near eradication of the disease; only 2 percent of the Dutch dairy farms have seropositive animals (AHS). The status of the dairy farms for *L. hardjo* is monitored by 3-monthly bulk-milk samples. Seropositive farms can only sell cattle for slaughter or calves for beef production. In 2000, *L. hardjo* positive farms are obliged to eradicate or treat all cattle to reach the free status. Direct losses (e.g. milk production losses, abortions) as results of a *L. hardjo* infection are calculated to amount between Dfl 34 and Dfl 150 per cow per year (Bennett, 1993).

S. dublin is a host-adapted serotype predominantly found in cattle. Salmonellosis is a potential zoonotic threat. *S. dublin* is an important salmonella serotype, affecting cattle in many countries all over the world. The disease causes deaths, abortions, diarrhea and limited growth and milk production (Nadalian and Bolourchi, 1998). The losses amount Dfl. 55 per cow per year (Visser et al., 1997). the Netherlands do not have an organized eradication program for *S. dublin*, but will have one in the near future. In Finland other salmonellosis species were already successfully eradicated (Aho et al., 1998). Nine percent of the Dutch dairy farms are seropositive for *S. dublin* in bulk milk (AHS). However, the disease prevalence is higher in some regions, such as the northern part of the Netherlands (Visser et al., 1993).

Farms need to be more closed to be able to remain free from eradicated infectious diseases. A more closed farm should limit the most important risk factors, first direct and lengthy animal contacts, followed by contacts with persons or animal transport vehicles, animal products and transmission by feed, vermin or air. The profitability of a more closed system will depend on the costs of the measures and on the potential losses as a result of introduction of diseases. For a profitable system the costs of the measures should be equal or lower than the potential benefits (i.e., the losses avoided). A study was started in 1995 to investigate the possibilities of a more closed system at Dutch dairy farms. The present paper describes the part of this study in which the probability of introduction of infectious diseases was monitored. The objectives of this paper are first to describe the more closed system on Dutch dairy farms. Secondly, the incidence of introduction of BHV1, BVDV, *S. dublin* and *L. hardjo* and the possible causes are described. Finally, the economics of a more closed system at dairy farms are discussed.

8.2 Materials and methods

8.2.1 Farms

Ninety-five SPF dairy farms were selected from a database of BHV1-free farms for a cohort study on the success of a more closed farming system. All farms were located in the northern part of the Netherlands because of logistic reasons. At the start of the study in March 1997, 93 farms were officially BHV1-free (two farms started vaccination before the beginning of the study) and all but three were also *L. hardjo* free. The farms had joined a BHV1 eradication program for which considerable (financial) efforts were needed and the farmers were motivated to remain free of BHV1. Their management was therefore expected to be more closed than the Dutch farms that were not (yet) BHV1-free. For two years (March 1997 until April 1999) the farms were visited every six months by the first author or by well trained students. During the two years farmers recorded data on their management with respect to introduction of diseases such as purchase of cattle and the possibility of over the fence contacts with neighbouring cattle. At every farm visit these recorded data were collected and discussed and additional data on various management practices were collected by means of questionnaires. The 95 SPF dairy farms were compared with farms that participated in an advisory project of the Dutch Farmers Organisation (LTO) to check external validity. The LTO project started in October 1998 and was focused on animal health. The objective of the project was to improve animal health management at dairy farms. The farms participated voluntary and were therefore not truly representative of Dutch dairy farms, but "early adopters". The SPF dairy farms were compared with the total group of LTO farms and the LTO farms from the northern part of the Netherlands.

8.2.2 Testing protocols

The 95 SPF farms were monitored closely with respect to introduction of BHV1, BVDV, *L. hardjo* and *S. dublin*. The AHS collected bulk milk samples for BHV1 on a monthly basis as part of the official national eradication program. The samples were analyzed with a gE-ELISA with high sensitivity and specificity (Wellenberg et al., 1998). The AHS also collected bulk milk samples at each dairy farm every three months to monitor the *L. hardjo* status using an antibody ELISA.

The BVDV status of the 95 SPF farms was monitored by blood samples in October 1997 and 1998 and bulk milk samples every 3 months. This blood-sampling scheme was according to the results of Houe (1992 and 1994). Blood samples were taken from 12 animals, five animals from 8-12 months old, three from 13-24 months old, 2 cows in second lactation and 2 higher lactation cows. Blood and milk samples were analyzed with an antibody ELISA. If no

antibodies were present among the 12 animals sampled and the bulk-milk samples were seronegative as well the farm was considered free of BVDV.
The status of *S. dublin* was also monitored during the study. Blood samples of all calves one to six months old were taken in April and October. Young calves are most sensitive for a *S. dublin* infection and are a good indicator group for the presence of *S. dublin* on a farm (Hoorfar et al., 1994). The samples were analyzed with two highly sensitive and specific antibody ELISAs, an indirect and a blocking ELISA (Hoorfar et al., 1994).

8.2.3 Data analysis

Descriptive statistics were carried out in SPSS 9.0. The total incidence rate (IRt) of all diseases per herd-year at risk was calculated as follows in formula 1.

$$\mathrm{IRt} = 0{,}5 * \sum \frac{\mathrm{IR_i}}{\#\text{ of farms at risk}} \qquad (1)$$

IR_i = incidence rate of diseases; BHV1, BVDV, *L. hardjo* or *S. dublin* in a two-year period.

Data were collected every six months and the farms were analysed on a 6 monthly basis. Every six months a farmer could have changed his/her management. Independent-sample t-test was used for continuous variables and a two-sided Fisher's exact test was used for categorical variables to test the association with an introduction of any of the four infectious diseases. Fisher's exact test was used since the numbers in some cells of the two-by-two tables were sparse (smaller than 5), and therefore the normality assumption of the χ^2 analysis was violated (Sokal and Rohlf, 1981). Exact tests are always reliable with regard to type 1 error, regardless of the size, distribution, sparseness, or balance of the data (Norusis, 1998). Statistical significance was defined at $P<0.10$ and a trend was assumed when $P<0.25$. The number of introductions was too small to perform a multivariable analysis. None of our models converged, probably due to too many empty cells. In exact regression only univariable models were significant and therefore we only report univariable results. The possible causes of the outbreaks will be discussed and the management measures to eliminate these causes will be used to calculate the costs of a more closed farming system.

8.2.4 Economic calculations

The costs for management measures for a more closed farming system were calculated using partial budgeting (Dijkhuizen and Morris, 1997). In partial budgeting the net revenue after the change in management were calculated with formula 2:

net revenue = extra benefits + costs foregone - benefits foregone - extra costs (2)

The net revenue of every management measure was calculated per year for the Dutch situation. Changes over time and uncertainty of the costs were not included in the calculations. The risk of each management factor was assumed to be equal, e.g. "no more purchasing of cattle" reduces the risk of introduction of infectious diseases as much as "providing protective clothing to visitors". The extra benefits of a disease-free status e.g. a higher value for sold cattle, were also not included in the calculations.
The avoided losses of introduction of BHV1 can be divided into losses caused by the outbreak and losses in the longer term. The milk production losses as result of a BHV1 outbreak at a BHV1-free farm were based on the results of Van Schaik et al. (1999). They found an average loss of 43.5 kilogram of milk per cow. For a 50-cow herd the average loss thus amounted to 2177 kilogram of milk, Dfl. 372. Furthermore, all cattle need to be vaccinated for BHV1 twice a year after an outbreak. The costs of vaccination for a 50 cow-herd and 50 replacements was estimated at 2 * Dfl. 8 * 100 = Dfl. 1600. Costs of the outbreak would increase considerably from abortions and deaths, and these costs were estimated to amount to Dfl. 1000. Finally, BHV1 had to be eradicated again, which would result in costs for blood sampling of cows and culling of seropositive cows. These losses were estimated to occur after a few years e.g. four year and added to approximately Dfl. 1000. The prevented losses for other infectious diseases were obtained from other studies.
The average losses of BVDV were based on a study of Groenendaal (1998). An average farm in that study was BVDV free, all age groups were in one barn and BVDV was introduced in youngstock. The losses included abortions, growth reduction, mortality, milk production losses, and reduced fertility.
The average losses of *L. hardjo* were based on a study of Bennett (1993). Half the costs of a hundred-cow dairy herd after initial infection were used. The costs accounted for were abortions, weak calves, mortality, drop in life-weight, and human infection. In the fifth year a sporadic outbreak was assumed by Bennett (1993).
The average losses of *S. dublin* were based on a study of Visser et al. (1997). The losses include abortions, growth reduction, mortality, extra veterinary costs, extra labour costs, and reduced fertility. In the present study the costs of an outbreak of *S. dublin* were assumed to be equal every year. Some basic figures and assumptions used for the calculations of the net revenue of a more closed farming system were based on KWIN-V (1999) and are the following:

- all economic calculations are done for a fixed quota system and the average farm has 50 milking cows and a 305-day milk production of 7500 kilograms per cow,
- the average price for a pregnant heifer is Dfl. 1800,

- the economic value of a kilogram of milk amounts to Dfl. 0.30 (milk price and opportunity costs minus feed costs),
- the costs of grazing cattle at other farms are Dfl.12.50 per week and a heifer needs 0.18 hectares per total youngstock life,
- the average price for rental of pasture is Dfl. 940 per ha,
- costs not mentioned above (e.g. coveralls, boots) are based on information obtained from farmers or extension officers,

A simple sensitivity analysis was carried out to elucidate the influence of the costs of management measures and the risk of introduction of diseases on the benefits of a more closed farm.

8.3 Results

8.3.1 Description of management on Dutch dairy farms

The average Dutch dairy farm has 53 milking cows and 29 hectares of pasture, 24% of the Dutch dairy farms were BHV1-free in 1999 (AHS). In Table 1 the 95 SPF dairy farms are compared with farms that participated in the advisory project of the LTO.

Table 1: Management with respect to introduction of diseases at Dutch dairy farms.

	LTO farms (n=980)	Northern LTO farms (n=252)	SPF farms (n=95)
Average number of adult cattle	68	80	63
Average hectares of pasture	32	45	38
Average number of professional visitors that handled cattle /week	-*	-*	5.2
BHV1-free	-*	-*	100%
Purchase of cattle in last two years (yes)	53%	43%	8%
Participation in cattle shows in last 2 years (yes)	-*	-*	2%
Visitors use protective clothing (yes)	59%	48%	52%
Applies manure from other farms (yes)	-*	-*	1%

*- = Unknown

The SPF farms were larger than the average Dutch dairy farm but smaller than the LTO farms. The farms were reasonably closed, only 8% purchased cattle and on 52% of the farms professional visitors used protective farm clothing.

8.3.2 *Probability of introduction of infectious diseases*

Figure 1 shows the introduction of all four diseases over the two-year study period.

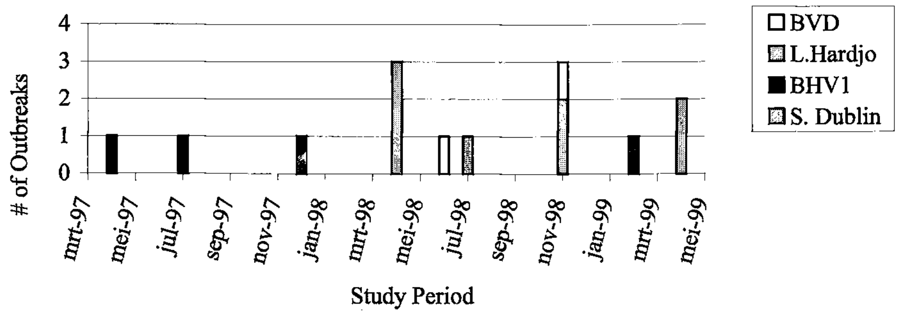

Figure 1: Introduction of four infectious diseases at 95 Dutch SPF dairy farms during a two year period.

8.3.2.1 BHV1

BHV1 was introduced at 4 dairy farms during the study period from March 1997 until April 1999. Two of the farms experienced a BHV1 introduction in the grazing season and cattle might have had the possibility to escape. Three of the four farms did not provide protective clothing to visitors. One of the 4 farms had a clear reduction in milk production and an increase in abortions during the BHV1 outbreak. At the other three farms the introduction of BHV1 was less severe and very little clinical signs were seen.

8.3.2.2 BVDV

Fifty farms were considered to be free of BVDV based on blood and milk samples. At two of these farms BVDV was apparently introduced. The farms were negative in blood and milk samples in the first year, but were positive in the second year. The possible cause of introduction of BVDV at one farm was the purchase of 12 pregnant heifers for replacement. The cattle at the other farm often had over-the-fence contacts with neighboring cattle. Both farms did not have other direct contacts with cattle from other farms and did not provide protective clothing to visitors. The farmers did not see any clinical signs of BVD.

8.3.2.3 *L. hardjo*

Ninety-two of the 95 BHV1-free farms were certified free of *L. hardjo* during the study. *L. hardjo* was introduced at one of the farms. The most likely cause was the purchase of two pregnant heifers from a farm with a positive *L. hardjo* status. The heifers were tested seronegative for *L. hardjo* when they arrived at the farm. However, after three months the bulk-milk sample was seropositive and investigation of individual cows revealed that, among others, the two purchased heifers were seropositive for *L. hardjo*. The economic consequences for the farm were not so much the direct losses (e.g. milk production losses), but the fact that *L. hardjo* positive farms are not allowed to trade cattle other than for slaughter or beef production.

8.3.2.4 *S. dublin*

A total of 85 SPF farms was at risk of becoming infected with *S. dublin*. In April 1998 three farms had positive samples, and in November 1998 as well as in April 1999 two farms had positive samples. The farms had already been negative for three, four or five rounds of samples respectively before positive samples were found and were therefore likely to have had an introduction of *S. dublin*. In total 8% of the farms experienced an introduction of *S. dublin* during the two-year study period. One of the farms with a *S. dublin* introduction in April 1999 also had an introduction of BHV1 in May 1997. Some farmers, but not all, observed clinical signs of an *S. dublin* infection.
None of the farms with a *S. dublin* introduction purchased cattle, participated in cattle shows, or applied manure of other cattle farms. Two of the farms grazed cattle together with cattle from other farms. This was a significant higher proportion than in the farms that stayed free of *S. dublin* (11% vs. 2%, P = 0.04). Only one of these seven outbreak farms did not have protective clothing. However, there was a trend that the professional visitors at the outbreak farms were less likely to use the protective clothing compared with farms that stayed free of *S. dublin* (P = 0.16).

8.3.3 Risk factors on farms with and without an introduction

Fourteen introductions of infectious diseases occurred on 13 farms out of the 95 during the study period, in which every farm had four 6-month observations. The total incidence rate per herd-year at risk was 0.09 with a 95% CI of 0.06 to 0.12. In Table 2, the management of the farms with an introduction of any of the diseases is compared with the management of the farms with no introductions. The non-outbreak farms were divided into two groups, all non-outbreak farms that differ in the number of diseases for which they were at risk and a group of non-outbreak farms that stayed at risk for all four diseases during the study period. Only the risk factors that had a $P<0.25$ are shown in Table 2. The farms did not significantly differ in the number of cattle, the number of hectares and the number of visitors that entered the barn.
The outbreak farms more often allowed cattle to return at the farm and less often made veterinarians wear protective clothing. The veterinarian is representative for a professional visitor and can be replaced in the model by any other professional visitor such as an AI

technician. There was a tendency that outbreak farms more often grazed cattle at other farms, and participated with cattle in shows, but these tendencies were not statistically significant.

Table 2: The incidence of management measures in four six-months periods at outbreak and non-outbreak farms.

Risk factors	Outbreak farms n=13*4 = 52	Non-outbreak farms n=82*4 = 328	Non-outbreak farms at risk for all 4 diseases n=33*4 = 132
The veterinarian always wears protective clothing	31%[a,b]	51%[a]	54%[b]
Cattle removed from the farm (e.g. for export) were allowed to return (e.g. when not sold)	6%[a,b]	1%[a]	1%[b]
Grazing of cattle at other farms	6%	2%	1%
Participation in cattle shows	4%	2%	1%

[a,b] Figures are percentages per column heading and figures with the same subscript are significantly different (P<0.10).

8.3.4 The economics of a more closed farming system

Although the 95 SPF farms were already more closed than the average farm in the Netherlands, 14% (95% CI 7 to 21%) suffered an introduction of infectious disease. These farms needed to become even more closed to prevent introduction of diseases. In Table 3, the costs to become more closed are shown for some management measures that seemed to have caused the introductions seemed to have caused the introductions at the 13 farms.

Table 3: The costs to obtain a more closed system at dairy farms.

Risk factors to be avoided	Options	Costs/yr (Dfl.)
Purchase	Rear one extra heifer, including costs for forage, but not for housing or labor	310
	Produce less milk	150
	Prolonged milking of a cow (sub-optimal replacement)	300
Grazing at other farms	Purchase of extra land (0.18 ha./heifer)	240
	Rear at own farm, including costs for forage and labor (costs per heifer per year)	92
Over the fence contacts with neighboring cattle	No grazing next to other cattle, suboptimal use of pasture (costs per ha.)	30
	Place a double fence (costs per ha.)	182
No protective clothing for professional visitors	Costs for protective clothing (3 coveralls, 3 pairs of boots)	270

To obtain a more closed farming system, the farmer has several options for every risk factor to be avoided. For example, a farmer who wants to have a more closed farming system can decide to have suboptimal replacement of cows (Dfl. 300), rear youngstock at own farm (12 animals * Dfl. 92 = Dfl. 1104), place a double fence (costs for 1 ha. are Dfl. 182), and supply protective clothing to professional visitors (Dfl. 270). The total costs for this farm will amount to Dfl. 1856 per year.

In Table 4 the costs over a five-year period of a more closed farm are compared with the average costs of introduction of infectious diseases in that period.

Table 4: The costs (in Dfl.) of a more closed farm compared with the average costs of introduction of infectious diseases at SPF farms.

Year	Costs of a more closed farm	Costs of BHV1 [a]	Costs of L. hardjo [b]	Costs of BVDV [c]	Costs of S. dublin [d]
1	1856	2972	7537	5824	4916
2	1856	1600	2649	1475	4916
3	1856	1600	1825	12452	4916
4	1856	1600	2706	5440	4916
5	1856	3400	4268	3028	4916
Total costs in five years (after introduction)	9280	11172	18985	28220	24580
Probability of introduction within five years (current study)		11%	3%	10%	21%
Average costs / 5 yr	9280	1201	516	2822	5162

[a] Based on Van Schaik et al., 1999.

[b] Bennett, 1993.

[c] Groenendaal, 1998.

[d] Visser et al., 1997.

Table 5: A sensitivity analysis on the benefits of a closed farming system (in Dfl.).

Scenarios	Costs for management	Avoided losses of diseases	Benefits of a closed farm
Basic scenario	9280	9701	421
Closed farm, but no elimination of grazing at other farms	3760	9701	5941
Incidence of introduction is 10% lower	9280	8731	-549
L. hardjo prevalence is 0	9280	9185	-95
Introduction of BHV1 on a farm	9280	11172	1892
Introduction of BHV1 and *S. dublin* on a farm	9280	35752	26472

The total costs over five years of a more closed farming system are Dfl. 9280. The average avoided losses of introduction of the infectious diseases under consideration are Dfl. 9701 for the same period of five years. The results of the sensitivity analysis are shown in Table 5.

The sensitivity analysis shows that the benefits of a more closed farming system will depend heavily on the costs of management measures to obtain a more closed farm and on the risk of introduction of infectious diseases. The higher the risk of introduction of infectious diseases the higher the benefits of a more closed farming system.

8.4 Discussion and conclusions

In our study only the introduction of BHV1, BVDV, *L. hardjo* and *S. dublin* was studied. These infections were chosen since data were readily available and/or introduction could be measured. The risk factors found in this study confirm the importance of direct animal contacts for introduction of infectious diseases. Allowing cattle to return at the farm (e.g. when not sold for export), grazing cattle at other farms and participation with cattle in shows will all facilitate direct contacts with other cattle and were found to be risk factors in other studies as well (Bennett, 1993; Van Wuijckhuise et al., 1997; Vaessen et al., 1998; Houe, 1999). In a previous study of Van Schaik et al. (1998) the presence of protective clothing was already found to be a protective factor. In the current study not just the presence but the use of protective farm clothing by professional visitors such as veterinarians was a protective factor. The possible cause of introduction of the infectious diseases was not known exactly for every case in the current study. However, in a study by Van Schaik et al. (2000) it was found that BHV1-free farms with cattle that breached or escaped to other cows and without protective clothing for visitors were more likely to have an introduction of BHV1. The causes for an introduction of *S. dublin* are hard to specify. Visitors and the grazing of cattle at other farms might play a role. However, other risk factors that were not included in the study such as access to ditch water or the prevalence of liver fluke might be involved as well (Vaessen et al., 1998).

8.4.1 Data quality

The cohort study at SPF dairy farms resulted in high quality management data on risk factors for introduction of BHV1. The regular visits at the farms stimulated the farmers to record data and recall bias for the relatively short period of six months was expected to be small. The study design allowed us to collect very detailed data on for example the number of visitors and their use of protective farm clothing. The farms were a selected group of SPF farms all located in the northern provinces of the Netherlands. The infection pressure for *L. hardjo* and *S. dublin* is higher in this part of the Netherlands (Visser et al., 1993). The incidence of introduction of these diseases therefore might be overestimated for Dutch dairy farms in general. The prevalence of BHV1 and BVDV was average for the Netherlands (Van

Wuijckhuise et al., 1993). The SPF farms had a more closed management at least with respect to purchase of cattle compared with the LTO farms and the probability of introduction of diseases might therefore be relatively low. However, although infection pressure of diseases may vary in different countries or areas the mechanism of the risk factors for introduction of diseases will be the same for any dairy farm. Risk factors found in this study will be important for any SPF dairy farm.

8.4.2 Misclassification

The sampling scheme used in this study might cause misclassification of outbreak and non-outbreak farms. Misclassification for BHV1 and *L. hardjo* is expected to be negligable. The repeated testing of bulk-milk samples with highly sensitive and specific tests will not result in false classification of farms. The tests carried out for BVDV and *S. dublin* are more likely to cause misclassification of farms. BVDV easily spreads within a farm between animals that are in close contact (Houe, 1999). At first introduction BVDV seroprevalence might be restricted to one specific age group. However, cattle from every age group were sampled in the conducted scheme. Farms were classified as BVDV-free farms if no antibodies were present in blood and bulk milk samples. We assumed that no virus carriers were present on those farms and we expect misclassification to be negligible (Houe, 1992; Houe, 1994). However, non-outbreak farms might be misclassified when BVDV was introduced, but had not yet spread to the milking herd and was not detectable in bulk milk samples.
Samples for *S. dublin* were taken at the farms every six months. Based on the results of the first two rounds farms were classified as seropositive or seronegative for *S. dublin*. Antibodies for *S. dublin* are only detectable from one or more weeks to approximately two months after infection (Da Roden et al., 1992). The chances for the detection of antibodies are highest in the susceptible group of young calves (Hoorfar et al., 1994). By sampling this group every six months we limited the number of false negative farms as much as possible. However, some of the farms we classified as *S. dublin* introduction farms might have had the bacteria at the farm already. We expect that misclassification of outbreak and non-outbreak farms will be random for the risk factors and that this nondifferential misclassification will lead to an underestimation of the importance of the risk factors. However, for the economic analysis overestimation of the probability of introduction of *S. dublin* might have led to overestimation of the costs (= avoided losses).

8.4.3 Data analysis

Fisher's exact test that was used in this study is a very conservative test, but it limits the type 1 error rate considerably (Sokal and Rohlf, 1981). Asymptotic theory does not provide this assurance. The risk factors found significant in the present study will therefore most likely be true risk factors, but as results of the conservativeness of the test the number of significant risk factors will be underestimated.

The data consisted of four repeated measures at every farm (four farm visits). The management in one period will be correlated with the next period, e.g. the presence of protective farm clothing. However, we treated the periods as independent observations to account for changes in management. Not all management measures will be correlated. Purchase of cattle, for example, is a rare event and will not occur every six months. By treating the observations as independent we might underestimate the variance of the risk factors and therefore especially increase the significance of those risk factors that are correlated between observations (i.e. protective clothing).

Most of the changes in management for a more closed farming system are relatively small events from a financial perspective. Partial budgeting is the best method for calculating relatively small changes in management (Dijkhuizen and Morris, 1997). However, it is difficult to account for longer time periods, and the varying times at which disease introductions occur relative to management factors.

8.4.4 Economic losses

The costs for the different management measures to obtain a more closed farming system were calculated for an average dairy farm. Costs of measures can differ greatly in time, per farm and per country. All economic calculations in this study were done for a fixed quota system. In a country without such a quota system growth will be important and the economics of specific measures of a more closed farming system might be different. The costs of introduction of infectious diseases will also depend on whether a country has (compulsory) eradication programs for diseases which might decrease the risk of introduction but might increase the costs of introduction as results of the renewed eradication efforts. The costs of an outbreak of *S. dublin* were assumed to be equal every year, but might be variable. A *S. dublin* infection can induce carrier states that will result in continuous losses, which was our assumption in the present study (Wray et al., 1989). An economically sensible advice can therefore only be given when based on the situation of a specific farm. The costs calculated for a more closed system in the study farms cannot be extrapolated to any dairy farm, but gives an indication of the level of the costs. The costs of a more closed farming system will occur every year. The losses due to infectious diseases will only occur in the event of an introduction. However, the present study showed that an introduction of an infectious disease was quite likely over a two-year period.

The risk of all management factors was assumed to be equal in this study. This assumption will not hold in reality. Purchase of cattle will for most diseases be more risky than e.g. visitors (Van Schaik et al., 1998; Lindberg and Alenius, 1999). The usefulness of a management measure in reducing the risk of introduction will depend on the costs per unit of decreased risk. Extra benefits of a more closed system are not accounted for, but might excist (e.g. a higher value of disease free cattle) and will increase the benefits of a more closed farming system.

In the sensitivity analysis only scenarios for a different closed farming system and for less introduction of infectious diseases were carried out. In the study only average costs for introduction of infectious diseases were included, but costs can be much higher or much lower. For risk-averse farmers the recurring costs of a more closed farm might be more attractive than the chance of very high costs as result of introduction of an infectious disease. A more elaborate sensitivity analysis should include the variability in costs and risk of introduction of infectious diseases and the variability around costs and risk of management measures.

Based on the results of this study one can conclude that a more closed system at these SPF dairy farms was economically profitable. On average, the costs for the management measures will be lower than the losses of introduction of infectious diseases.

8.4.5 Clinical signs

The introductions vary in the amount of clinical signs and as a result of that in economic losses. The average losses of infectious diseases mentioned by other studies might therefore not occur on farms with subclinical outbreaks. The registrations of clinical signs were done by the farmers and were not supported by other sources. Therefore, the reports of clinical signs might be biased. Some farmers might have falsely attributed clinical signs to the introduction, while other farmers might not have recognised the clinical signs. However, for a disease such as BVDV the losses might occur in a later stage when susceptible pregnant cattle are infected and abort or produce BVDV carriers (Houe, 1999). The one farm with a clinical BHV1 outbreak that caused milk production losses and abortions seemed to be proven right by looking at historic milk production data and the higher number of abortions within a short period after the introduction. The other three farms did not mention clinical signs at all or mentioned some mild respiratory signs only. Another study showed that this was seen more often at Dutch dairy farms (Van Nieuwstadt and Verhoeff, 1983). In the case of *S. dublin* and *L.hardjo* introductions clinical signs might not have been recognized or will occur in a later stage as well.

8.4.6 Concluding remarks

Although the SPF farms already had a more closed farming system, the incidence of introduction of infectious diseases was high, 14 introductions on 13 farms with 320 herd-years at risk during a two year period. The introductions will not be a random event. We expect that the farms that did not have an introduction in the two year study period are less likely to have an introduction in the future. Based on previous studies we think that this is because of their situation, e.g. a low cattle density area and situated relatively far from other cattle farms (Van Wuijckhuise et al., 1997; Van Schaik et al., 1998), but also because they tend to be more closed farms. The study supports this last assumption by showing that the non-outbreak farms were significantly more closed than the outbreak farms. Farmers should adopt a more closed farming system to prevent economic losses as results of introduction of infectious diseases. Direct animal contacts with other cattle should be avoided and professional visitors should be convinced of the necessity to put on protective clothing before handling cattle. The economic calculations show that this will be profitable for an SPF farm.

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References

Aho, R., Nauholz, H., Hankonen, P., Nyberg, M. and Tirkkonen, T., 1998. The time required for the elimination of bovine salmonella infection. In: Caple, I.W. (ed) *Proceedings of the XX World Association for Buiatrics Congress*, Sydney, July 1998: 875-877.

Anderson, M. and Blanchard, P., 1989. The clinical syndromes caused by Salmonella infection. *Veterinary Medicine* 84: 816-819.

Bennett, R.M., 1993. Decision support models of leptospirosis in dairy herds. *The Veterinary Record* 132: 59-61.

Bolin, C.A. and Alt, D.P., 1989. Clinical signs, diagnosis, and prevention of bovine leptospirosis. In: Caple, I.W. (ed) *Proceedings of the XX World Association for Buiatrics Congress*, Syndey, July 1998: 899-904.

Da Roden, L., Smith, B.P., Spier, S.J. and Dilling, G.W., 1992. Effect of calf age and Salmonella bacterin type on ability to produce immunoglobins directed against Salmonella whole cells or lipopolysaccharide. *American Journal of Veterinary Research* 53: 1895-1899.

De Verdier Klingenberg, K., Vagsholm, I. and Alenius, S., 1999. Incidence of diarrhea among calves after strict closure and eradication of Bovine viral diarrhea virus infection in a dairy herd. *Journal of the American Veterinary Medicine Association* 214: 1824-1828.

Dijkhuizen, A.A and Morris, R.S., 1997. Animal Health Economics. Principles and applications. Post Graduate Foundation in Veterinary Science, Sydney and Wageningen Press, Wageningen.

Franken, P., Sol, J. and Wentink, G.H., 1986. BVD (bovine virus diarrhea) and IBR (infectious bovine rhinotracheitis): serologic studies on 35 farms. *Tijdschrift voor Diergeneeskunde* 111:-1205-1207.

Groenendaal, H., 1998. Simulation of the costs and benefits of a BVDV eradication program at dairy farms. MSc thesis, Wageningen University, The Netherlands, 67pp.

Hage, J.J., Schukken, Y.H., Dijkstra, T., Barkema, H.W., van Valkengoed, P.H.R. and Wentink, G.H., 1998. Milk production and reproduction during a subclinical bovine herpesvirus 1 infection on a dairy farm. *Preventive Veterinary Medicine* 34: 97-106.

Hoorfar, J., Feld, N.C., Schirmer, A., Birsch, V. and Lind, P., 1994. Serodiagnosis of *Salmonella dublin* infection in Danish dairy herds using O-antigen based enzyme-linked immunosorbent assay. *Canadian Journal of Veterinary Research* 58: 268-274.

Houe, H. and Meyling, A., 1991. Prevalence of bovine virus diarrhea (BVD) in 19 Danish dairy herds and estimation of incidence of infection in early pregnancy. *Preventive Veterinary Medicine* 11: 9-16.

Houe, H., 1992. Serological analysis of a small herd sample to predict presence or absence of animals persistently infected with bovine virus diarrhea virus (BVDV) in dairy herds. *Research of Veterinary Sciences* 53: 320-323.

Houe, H., Pederson, K.M. and Meyling, A., 1993. The effect of bovine virus diarrhea virus (BVDV) infection on conception rate. *Preventive Veterinary Medicine* 15: 117-123.

Houe, H., 1994. Bovine virus diarrhea virus: detection of Danish dairy herds with persistently infected animal by means of a screening test of ten youngstock. *Preventive Veterinary Medicine* 19: 241-248.

Houe, H., 1999. Epidemiological features and economical importance of bovine virus diarrhea virus (BVDV) infections. *Veterinary Microbiology* 64: 89-107.

Kuiper, C.J. and Martens, M.R.T.M., 1994. Specific pathogen free health programs. *Tijdschrift voor Diergeneeskunde* 119: 390-393.

KWIN-V 1998-1999. Quantitative information of animal production . Research station for cattle, she, and horse husbandry. Lelystad, The Netherlands.

Lindberg, A.L.E. and Alenius, S., 1999. Principles for edication of bovine viral diarrhea virus (BVDV) infections in cattle populations. *Veterinary Microbiology* 64: 197-222.

Moerman, A., Straver, P.J., de Jong, M.C.M., Quak, J., Baanvinger, T.H. and van Oirschot, J.T., 1994. Clinical consequences of bovine virus diarrhea virus infection in a dairy herd: a longitudinal study. *Veterinary Quarterly* 16: 115-119.

Nadalian, M.G. and Bolourchi, M., 1998. Different clinical aspects of Salmonellosis in calves. In: Caple, I.W. (ed) *Proceedings of the XX World Association for Buiatrics Congress*, Syndey, July 1998: 897-898.

Norusis, M.J., 1998. SPSS 8.0 Guide to data analysis. Prentice-Hall, Inc., Upper Saddle River, New Jersey, 563pp.

Nuotio, L., Juvonen, M., Neuvonen, E., Sihvonen, L. and Husu-Kallio, J., 1999. Prevalence and geographic distribution of bovine viral diarrhea (BVD) infection in Finland 1993-1997. *Veterinary Microbiology* 64: 231-235.

Pasman, E.J., Dijkhuizen, A.A. and Wentink, G.H., 1994. A state-transition model to simulate the economics of bovine virus diarrhea control. *Preventive Veterinary Medicine* 20: 269-277.

Sokal, R.R. and Rohlf, F.J., 1981. Biometry 2nd edition. WH Freeman and Company, San Francisco, 859 pp.

Sørensen, J.T., Enevoldsen, C. and Houe, H., 1995. A stochastic model for simulation of the economic consequences of bovine virus diarrhea virus infection in a dairy herd. *Preventive Veterinary Medicine* 23: 215-227.

Stelwagen, J. and Dijkhuizen, A.A., 1998. BVD-outbreak can be costly: a case farm. *Tijdschrift voor Diergeneeskunde* 123: 283-86.

Straub, O.C., 1991. BHV1 infections: relevance and spread in Europe. *Comparative Immunology Microbiology and Infectious Diseases* 14 :175-186.

Van Nieuwstadt, A.P. and Verhoeff, J., 1983. Epidemiology of BHV1 virus infections in dairy herds. *Journal of Hygiene, Cambridge* 91:309-318.

Van Schaik, G., Dijkhuizen, A.A., Huirne, R.B.M., Schukken, Y.H., Nielen, M. and Hage, J.J., 1998. Risk factors for existence of bovine herpesvirus 1 antibodies on nonvaccinating Dutch dairy farms. *Preventive Veterinary Medicine* 34: 125-136.

Van Schaik, G., Shoukri, M., Martin, S.W., Schukken, Y.H., Nielen, M. and Dijkhuizen, A.A., 1999. Modeling the effect of an outbreak of BHV1 on herd-level milk production on Dutch dairy farms. *Journal of Dairy Science* 82: 944-952.

Van Schaik, G., Schukken, Y.H., Dijkhuizen, A.A., Barkema, H.W. and Benedictus, G., 2000. Introduction of BHV1 at certified BHV1-free Dutch dairy farms. Submitted.

Van Wuijckhuise, L., Bosch, J., Franken, P., Hage, J.J., Verhoeff, J. and Zimmer, G., 1993. The prevalence of Infectious Bovine Rhinotracheitis (IBR) in the Netherlands. In: Elbers, A.R.W. (ed), *Proceedings 6th meeting of the Dutch Soc for Vet Epidemiol Economics.* Boxtel: 7-16.

Van Wuijckhuise, L., Bosch, J., Franken, P., De Wit, J., Frankena, K. and Elbers, A., 1997. Some epidemiological characteristics of bovine herpesvirus 1 (BHV1) infections as determined by bulkmilk testing of all Dutch dairy herds. *Epidemiologie et Sante Animale*, special issue; 31-32;11.13.1-3

Vaessen, M.A., Veling, J., Frankena, K., Graat, E.A.M. and Klunder, T., 1998. Risk factors for Salmonella dublin infection on dairy farms. *Veterinary Quarterly* 20: 97-99.

Visser, I.J.R., Veen, M., van der Geissen, J.W.B., Peterse, D.J. and Wouda, W., 1993. *Salmonella dublin* in dairy farms in the north of the Netherlands. *Tijdschrift voor Diergeneeskunde* 118: 84-87.

Visser, S.C., Veling, J., Dijkhuizen, A.A. and Huirne, R.B.M., 1997. Economic losses due to *S. dublin* in dairy cattle. In: Kristensen, A.R. (ed), Proceedings of Dutch / Danish symposium on animal health and management economics. Copenhagen, January 1997, 143.

Vonk Noordegraaf, A., Buijtels, J.A.A.M., Dijkhuizen, A.A., Franken, P., Stegeman, J.A. and Verhoeff, J., 1998. An epidemiological and economic simulation model to evaluate the spread and control of infectious bovine rhinotracheitis in the Netherlands. *Preventive Veterinary Medicine* 36: 219-238.

Wellenberg, G.J., Verstraten, E.R.A.M., Mars, M.H. and Van Oirschot, J.T., 1998. Detection of bovine herpesvirus 1 glycoprotein E antibodies in individual milk samples by enzyme-linked immunosorbant assay. *Journal of Clinical Microbiology* 36: 409-413.

Wentink, G.H. and Dijkhuizen, A.A., 1990. Economic consequences of an infection with the Bovine Virus Diarrhea virus (BVD-virus) in 15 dairy farms. *Tijdschrift voor Diergeneeskunde* 115: 1031-1040.

Wray, C., Wadsworth, Q.C., Richards, D.W. and Morgan, J.H., 1989. A three-year study of *Salmonella dublin* infection in a close dairy herd. *The Veterinary Record* 124: 532-535.

Chapter 9

An economic model to calculate the costs and benefits of a closed system at dairy farms for on-farm decision support.

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Abstract

A more closed farming system can be a good starting point for eradication of infectious diseases. The economic implications of a more closed farming system will not always been obvious to farmers. The management decisions need to be made for different parts of the farm and are farm-specific. A model to support these decisions was developed as a first attempt to model the economic consequences of a more closed farming system and a simple static and deterministic design was chosen. The risk factors in the model were solely based on BHV1, but the losses of introduction of other infectious diseases (i.e. BVDV, *L. hardjo*, and *S. dublin*) were added to the model. The model was verified and partly validated and a sensitivity analysis was carried out to obtain insight into the model behaviour.

A 55-cow dairy farm that refrained from purchasing cattle, provided protective clothing to professional visitors and a temporary worker, and build and maintain a double fence at six hectares of land to prevent over the fence contacts had to spend Dfl. 899 per year, and Dfl. 4495 in five years. The probability of disease introduction was decreased by 74%. The prevented losses for disease introduction amounted to Dfl. 7033 over five years. The benefits of this more closed farming system were Dfl. 2538.

A more closed farming system was still beneficial when a sanitary barrier was used instead of just protective clothing, when the probability of introduction of infectious diseases was decreased, and when odds ratios in the model were replaced by more conservative relative risks. The benefits became negative when a farm had to build and maintain a double fence at 12 ha. instead of 6 ha., when the probability of introduction of all diseases was decreased with 50%, and when the calculations were solely based on BHV1.

A probabilistic or stochastic model would have been a better representation of the real world, but the deterministic model already was a satisfying tool to support on-farm decisions.

9.1 Introduction

The Netherlands strives for a higher animal health status by implementing disease eradication, starting with Bovine Herpesvirus type 1 (BHV1). Several countries in the EU are free of this virus for which export restrictions are established (Noordegraaf et al., 1998). BHV1 causes the disease called infectious bovine rhinotracheitis (IBR) as well as infectious pustular vulvovaginitis (IPV). At first introduction in the Netherlands in the 70s BHV1 caused severe clinical signs. However, in the early 80s outbreaks became subclinical. Approximately 55% of the dairy farms and 40% of the cattle was seropositive for BHV1 in 1996. Approximately 17% of the farms vaccinated against BHV1 at that time and these seropositive cows could not be distinguished from infected cows (Van Wuijckhuise et al., 1997). In 1998 a compulsory eradication program for BHV1 was started in the Netherlands (Vonk Noordegraaf et al., 1998). The responsibility for eradication is at the farm level implying that individual farmers are responsible for their animals' health. In 1999 already one third of the cattle farms in the Netherlands were certified BHV1-free. For a successful eradication program farms should remain BHV1-free and this can be ensured by a more closed farming system. In addition, a more closed farming system may prevent introduction of other diseases such as Bovine Viral Diarrhoea Virus (BVDV), *Leptospira interrogans serovar hardjo* (*L. hardjo*) and *Salmonella enterica subsp. enterica serotype Dublin* (*S. dublin*) and can be a good starting point for eradication of these infectious diseases.

A dairy farm cannot be closed completely; there are always necessary contacts with the outside world, through veterinarians, AI-technicians, and cattle grazing outside. In this paper a more closed farming system was defined as a farm that rules out the possibility of direct contact with cattle from other farms. Secondly, the farmer obliges professional visitors to put on protective farm clothing before handling cattle. In this paper professional visitors are visitors that enter the animal area of the barn and come into contact with cattle (e.g. veterinarians, AI-technicians, cattle traders). Protective farm clothing is defined as coveralls or overcoats and boots that are provided by the farmer to visitors before handling cattle. A sanitary barrier is a covered area outside the barn in which visitors can change from their own clothes to protective farm clothing. A sanitary barrier has a "dirty" side, where visitors change clothing and a "clean" side, where visitors wear protective clothing and can enter the barn.

The economic implications of a more closed farming system will not always be obvious to farmers. Management adaptations need to be made for different parts of the farm and are farm-specific. The management measures to obtain a more closed farming system will differ in effectiveness for risk reduction and costs. Furthermore, the possible benefits of a more closed farming system (= avoided losses of disease introduction) will also differ depending on the farm characteristics. An economic model can provide better insight into this complex management problem. For effective on-farm decision support the input of such economic model has to be farm specific. It should represent the situation on the farm, and should be able to evaluate a wide range of strategies. Furthermore, the output of the model needs to be recognisable and applicable for the farmer (Jalvingh, 1992).

Management strategies can be evaluated using simulation or optimisation. Optimisation models are generally developed for a specific situation and are less suited to study the consequences of a wide range of management strategies (Jalvingh, 1992). Furthermore, the goal of the current economic model was to give farmers insight into the possibilities of a more closed farming system. Due to the farm situation the final solution of the model does not necessarily have to be the optimal solution from a financial or risk perspective. A simulation model was therefore preferred to model the economic consequences of a more closed farming system.

A deterministic design is the most straightforward and simple modelling approach. Other, more elaborate approaches are probabilistic or stochastic modelling. In probabilistic modelling probability distributions are included to model uncertainty. Random number generators are added when a stochastic modelling approach is used. In the deterministic approach the resulting average performance of the farm is always equal for the same input (Jalvingh, 1992). Chance and uncertainty are important features of disease introduction. However, the present model was developed as a first attempt to model the economic consequences of a more closed farming system and therefore a simple static deterministic design was chosen.

One of the most difficult problems in modelling is to determine whether a simulation model is an accurate representation of the actual system being studied, i.e. whether the model is valid. Validation of a model can be divided in three steps; verification, validation, and establish credibility. Verification determines that a computer model performs as intended, and includes debugging the computer program. Validation is concerned with determining whether the conceptual simulation model is an accurate representation of the system under study. A simulation model is credible when its results are accepted by the target group and used as a tool to aid decisions (Law and Kelton, 1991).

The objective of the present study is to describe and discuss an economic model for on farm decision support. A sensitivity analysis is included and gives more insight into the model behaviour. Finally, the economic consequences of several more closed farming systems are discussed.

9.2 Description of the economic model

An economic model was developed to calculate the costs and benefits of a more closed system at dairy farms. The economic model is a static model, which means that time was not included as a variable. Furthermore, the model is deterministic and contains no probability distributions to model uncertainty in the behaviour of the system. The input for the model was obtained from previous studies (Van Schaik et al. (1998, 1999a, 1999b, 2000a, 2000b)) that focused on introduction of BHV1. The risk factors in the model are therefore solely based on BHV1, but the losses of introduction of other infectious diseases (i.e. BVDV, *L. hardjo*, and *S. dublin*) were added to the model. The study resulted in the odds ratios (OR) of the risk factors. When risk factors were not significant in the multivariable model an estimate of the OR from the univariable results was used in the economic model. The ORs were used in the model as an approximation of the relative risks (RR), which would represent the strengths of the associations better. Therefore, the RR were calculated from the OR based on the criteria of Beaudeau and Fourichon (1998). The implication of RR replacing OR in the model is discussed further on in the present study. Risk factors for introduction of other infectious diseases were not included in the model, but the potential losses as result of introduction of these diseases, as calculated in Van Schaik et al. (2000b), were used to calculate the benefits (= avoided losses) of a more closed farming system. The model was divided in four modules: A module for general farm characteristics ("farm input module"), a module for the management measures ("management module"), a module for the losses as results of introduction of BHV1 ("losses module"), and finally a module in which chance of introduction, costs of the management measures and losses of introduction of BHV1, BVDV, *L. hardjo* and *S. dublin* were combined to calculate the possible benefits of a more closed farming system ("results module").

9.2.1 Farm input module

The farm input module contains information on BHV1-status, farm size, farm intensity, number of sold cattle, and the distance to neighbouring cattle farms. The BHV1-status in the model were: BHV1-free, only youngstock BHV1-free, and vaccinating for BHV1. A BHV1-free farm will differ from vaccinating farms with respect to management, probability of BHV1 introduction and losses. The information from this module was used as input for the management and losses modules to calculate the costs for specific management measures and the losses of introduction of BHV1.

9.2.2 Management module

The management module in the model consists of numerous management measures, which may eliminate or reduce the risk of the risk factors. A farmer can select a management measure according to the farm situation, the risk reduction of a measure and the costs of a management measure. In this way all calculations were farm-specific.

The costs for management measures for a more closed farming system were calculated by using partial budgeting (Dijkhuizen and Morris, 1997). With partial budgeting the net revenue after the change in management were calculated with formula 1:

$$\text{net revenue} = \text{additional returns} + \text{reduced costs} - \text{returns foregone} - \text{extra costs} \qquad (1)$$

The net revenue of every management measure was calculated per year for the Dutch situation. Changes over time and uncertainty of the costs were not included in the calculations. Each management factor was assumed to reduce the risk of a risk factor with a certain percentage between 0% and 100%. To reduce the risk of purchase of cattle a farmer can choose e.g. "rearing extra heifers instead of purchasing", which reduces the risk of

purchase to 0% and costs Dfl. 310 per reared animal or the farmer can "test purchased cattle for diseases", which reduces the risk of purchase with 40% and costs Dfl. 70 per purchased animal. See the appendix for some more examples. The reduction of the risk per adapted management factor was not based on scientific results, but was estimated based on common sense.
Some basic figures and assumptions used for the costs calculations were based on KWIN-V (1999) and other costs (e.g. costs for coveralls, boots) were based on information obtained from farmers or extension officers. All economic calculations assumed a fixed quota system for milk and when the specific farm information could not be used an average farm was used instead with 50 milking cows and a 305-day milk production of 7500 kilograms per cow.

9.2.3 Losses module

In the losses module losses of introduction of BHV1 were calculated for the farm-specific situation. The losses of introduction of BHV1 can be divided into losses caused by the outbreak and losses in the longer term. The milk production losses as a result of a BHV1 outbreak at a BHV1-free farm were based on the results as described in Van Schaik et al. (1999b). The average loss was 43.5 kilogram of milk per average cow present during the outbreak period of nine weeks. Furthermore, the farmer needs to vaccinate all cattle for BHV1 twice a year. The costs of two vaccinations per animal will amount to 2 * Dfl. 8 = Dfl. 16 per year. Costs will increase considerably when an introduction causes abortions and deaths. In the model some estimated figures were used based on a study of Nooijen (1998). Furthermore, farms will have to eradicate BHV1 again after approximately four years, which will result in costs for blood sampling of cows and culling of seropositive cows. The returns foregone, as result of a higher value for disease free sold cattle, were also included in the calculations.

9.2.4 Results module

In the results module the risk of introduction of BHV1 into the farm was calculated before and after measures to reduce the risk were taken. The reduced chance of introduction of BHV1, the costs of the more closed farming system, and the avoided losses of BHV1 were weighted to obtain the potential benefits (= avoided losses - costs of measures) of the more closed farming system. The costs of introduction of BVDV, *L. hardjo* and *S. dublin* on an average farm were also included in this module and obtained from other studies (Groenendaal, 1998; Bennett, 1993; Visser and Veling, 1997). All costs in this module were calculated over a five-year period because costs of measures as well as losses of infectious disease introduction persist over a longer period. It was assumed that BHV1 was going to be eradicated again four years after an outbreak-year, and a five-year period was therefore chosen in the model.

9.2.5 Validation of the model input

A first attempt was made for verification and validation of the economic model. The credibility of the model was not yet established sufficiently but will be in due time. A formal statistical validation between model output and real life data was not feasible within this study.

The input of the economic model was verified by on-site questionnaires performed in 1999 at 68 initially BHV1-free dairy farms, of which two experienced an outbreak of BHV1. The farms were participants in the cohort study described in Van Schaik et al. (2000b). The farmers were visited and questioned about the management measures they had taken to become a more closed farm. Furthermore, an estimate of the costs of the measures was obtained from the farmers to validate the costs in the management module. Finally, the representativeness of the model was discussed with these farmers, i.e. whether all possible management options were included and whether the model represented a real farm. Validation of the model with a sufficient number of BHV1 vaccinating dairy farms needs still to be carried out. However, the model is expected to be less valid for vaccinating farms that will have different probability of introduction and different losses. Therefore, the focus in this paper will be on the use of the model for BHV1-free farms.

The face validity of the model was tested by presenting the model and its results at eight group meetings of 125 farmers. The model was slightly adapted based on the reactions of the farmers on these presentations. In the near future the credibility of the model will be tested with individual farmers. The output of these real-life farms will be discussed with the farmer to establish the credibility of the model.

9.2.6 Sensitivity analysis

Several scenarios were tested to determine their influence on the profitability of a more closed farming system. The base scenario is presented in paragraph 2.1 through 2.4. A drawback of the model is that the base probability of introduction of diseases is based on one cohort study of farms in the northern part of the Netherlands (Van Schaik et al., 2000b). The farms in that study were mostly free of BHV1 and *L. hardjo* and were relatively closed. In the sensitivity analysis the probabilities of introduction of diseases are varied to represent different probabilities for other situations in other areas.

The risk of visitors was expected to be considerable, based on the results in previous study is (Van Schaik et al., 1998; 1999a). Protective clothing was compared with a sanitary barrier to determine the influence of an increased reduction of risk through professional visitors. A very common risk factor in the Netherlands is that cattle graze close to neighbouring cattle. Farms that are favourably situated (i.e. no adjacent cattle) will have much lower costs to reduce the risk then farms that are unfavourably situated (i.e. much pasture adjacent to neighbouring cattle). In the sensitivity analysis a less favourable situation was suggested by doubling the amount of pasture adjacent to other cattle. Finally, the odds ratio (OR) in the model were replaced by relative risks (RR) to investigate the effect of the overestimation of the strength of the associations.

9.3 Results

9.3.1 Validation

In the Netherlands farms produce under a milk quota system. For many farmers the reason to purchase cattle was when they expected not to fill their milk quota. The study showed that six BHV1-free farms purchased BHV1-free cattle. Most farmers (66%) would not purchase cattle but retained cattle longer than economic viable (sub-optimal replacement). The other farmers would lease surplus quota or not fill the quota.

None of the farmers participated in cattle shows or grazed cattle at other farms. In the previous grazing season in 1998 56% of the farmers grazed cattle close to cattle from neighbours. Eighteen percent of the farmers did not take measures to prevent direct contacts over the fence. Thirty-nine percent of the farmers had placed a permanent double fence and 24% a temporary double fence that ensured enough distance to prevent direct cattle contacts. The other farms (19%) would not use the plots for grazing (e.g. mow the plots) or grow maize on plots where neighbouring cattle would graze adjacent.

All farms took preventive measures for professional visitors. Nine percent of the farms had a sanitary barrier with a clean and dirty way including protective clothing and boots. The other farms had clothing and boots (72%) or just a disinfection basin (19%). On 18% of the farms a temporary worker was employed who also worked at other farms. All workers used protective farm clothing that remained on the farm.

Farmers agreed on most costs in the model except the higher price of BHV1-free bulls that are sold to breed at other farms and the costs of a sanitary barrier. Farmers thought the extra costs of a BHV1-free breeding bull to be Dfl. 125 instead of Dfl. 200. They thought the costs of a sanitary barrier to be Dfl. 3800 instead of Dfl. 2300. These figures were changed in the model.

9.3.2 *Results of the model*

A fictitious farm based on the results from the questionnaire was entered in the model to calculate the costs and benefits of a more closed system for this farm. The input for each module and the results of the calculations are given in the next paragraphs.

9.3.2.1 Farm input module

9.3.2.1.1 General farm information

- BHV1-free 55-cow dairy farm.
- Farm intensity <2.5 adult cow equivalent/ha. (GVE/ha.)
- Each year on average two heifers are sold for export.
- No sale of breeding bulls.

9.3.2.1.2 Risk factors

	Farm input	OR	RR [d]
Distance to other cattle farms (in meters)	300	0.70 [a]	0.80
The number of purchased BHV1-free heifers (per year)	1	1.32 [a]	1.18
Participation in cattle shows (yes/no)	0	3.54 [a]	1.88
Cattle rejected for e.g. export is returned to the farm (yes/no)	0	4.59 [b]	-
Cattle is grazed at other farms or other cattle at the own farm (yes/no)	0	1.28 [c]	-
Hectares of land where cattle was grazed adjacent to neighbouring cattle (ha.)	6	1.22 [c]	1.12 [c]
Youngstock is served by a purchased bull (yes/no)	0	1.28 [c]	-
The number of times professional visitors come in the barn (per year)	104	1.004 [a]	1.002
A temporary worker that also works at other farms (yes/no)	1	3.27 [a]	1.76

[a] Van Schaik et al. (1998),

[b] Van Schaik et al. (1999a),

[c] estimated based on the univariable results of Van Schaik et al. (1998, 1999a, 2000),

[d] estimated based on the correction criteria of Beaudeau and Fourichon (1998).

9.3.2.2 Management module

Some management measures to reduce the risk*:	Estimated remaining risk	Costs of measures (in Dfl.)
No more purchase, but sub-optimal replacement of one cow.	0%	110
Double fencing of 6 ha.	20%	402
Providing protective clothing and boots to professional visitors.	40%	297
Providing protective clothing and boots to temporary workers.	40%	90
Total costs per year		899
Total costs per five years		4495

* these management measures are just a few of the numerous options in the model to reduce or eliminate the risk, e.g. "purchase" has 13 options, "cattle shows" 9 options, et cetera.. The calculations of the costs are provided in the appendix.

9.3.2.3 Losses module

Costs of introduction of BHV1	Costs /cow (in Dfl.)	# of cattle	Costs per farm per year (in Dfl.)
Milk production losses [a]	6.50	55	359
Number of abortions [b]	550	0.5	275
Reduced growth youngstock [b]	5	55	275
Vaccination of 55 cows and 55 youngstock twice a year (2*Dfl. 8) [b]	16	110	1760
Reduced value of sold heifers [c]	200	2	400
Total costs in first year of outbreak			3069
Costs of vaccination and reduced value heifers in second, third, and fourth year			5280
Eradication of BHV1 of the farm in fifth year			1000
Total costs in five years			9349

[a] Van Schaik et al. (1999b)

[b] estimations of Nooijen (1998)

[c] information obtained from farmers in the present study

9.3.2.4 Results module

No measures	BHV1	BVDV	*L. hardjo*	*S. dublin*	Totals
Average costs	9349	28220	18985	24580	
Incidence [a]	11%	10%	3%	21%	
Losses over five years	1028	2822	516	5162	9528
Measures					
Remaining risk	26%	26%	26%	26%	
Incidence [b]	2.9%	2.6%	0.8%	5.5%	
Losses over five years	271	734	148	1342	2495
Total avoided losses over five years					7033
Total costs over five years of a more closed farming system					4495
The benefits over five years of a more closed farming system					2538

[a] The probability of introduction (=incidence) is based on the study of BHV1-free farms (Van Schaik et al., 2000b).

[b] Incidence after measures = incidence before measures * remaining risk.

9.3.2.5 Sensitivity analysis

The results of the sensitivity analysis are shown in Table 1. The sensitivity analysis shows that the benefits of a more closed farming system become negative when a farmer has to fence 12 ha. instead of 6 ha. of pasture to prevent over the fence contacts. The probability of introduction of infectious diseases increases and therefore the avoided losses increase. At the same time the costs of placing a double fence increases. Overall, the benefit of a more closed farm in that situation becomes negative (-138), which means that the costs of management measures were higher than the avoided losses.

Table 1: The results of a sensitivity analysis of an economic model for the costs and benefits of a more closed farming system

Scenario	Losses of diseases before measures	Losses of diseases after measures	Costs of a more closed farm	Benefits of a more closed farm in 5 years
Base scenario	9528	2495	4495	2538
A sanitary barrier instead of only protective clothing	9528	2108	6425	995
Grazing close to other cattle at 12 ha. instead of 6 ha.	9528	3161	6505	-138
The probability of introduction of BHV1 and *L. hardjo* is zero	7984	2076	4495	1413
The probability of introduction of *S. dublin* is 50% lower	6947	1824	4495	628
The only disease that can be introduced is BHV1	1028	271	4495	-3738
The probability of introduction of all diseases is 50% lower	4764	1248	4495	-979
OR replaced by RR	9528	3737	4495	1296

Another scenario in which the benefit becomes negative is when the probability of introduction of all diseases is 50% lower. The avoided losses are half as big as in the base situation.

Finally, when the only disease that can be introduced at the farm is BHV1, the benefit of a more closed farm is also negative. A more closed system solely for BHV1 prevention is clearly not economically attractive.

When a sanitary barrier is built the costs of a more closed farm will increase to Dfl. 6425 in five years. The probability of introduction was lower than in the base situation with protective clothing only. In this scenario a more closed farm is still beneficial.

A more closed farm is also beneficial when the probability of introduction of BHV1 and *L. hardjo* is set to zero or when the probability of introduction of *S. dublin* is 50% lower.

Replacing the ORs with RRs decreases the estimated profitability of a more closed farming system, but the profitability remains positive.

9.4 Discussion

In several situations a more closed farming system was profitable. The sensitivity analysis showed that an unfavourable location of a farm, close to other cattle farms, can increase the costs to avoid over the fence contacts considerably. The model was not sensitive for changing the risk estimates from ORs to RRs. A more closed farming system will only be economically attractive when it prevents introduction of more diseases. However, the management factors in the model will decrease the probability of introduction of other diseases as well, and therefore the avoided losses of introduction of other diseases were included in the model. The model is sensitive for the magnitude of the losses of infectious diseases introduction. The profitability of a more closed farm will decrease when the avoided losses decrease.

9.4.1 Economics

The economic model is a static model, which means that time was not included as a variable. Furthermore, the model is deterministic and contains no probability distribution to model uncertainty in the behaviour of the system. This simple modelling approach has its advantages and disadvantages. The advantage is that the model was relatively simple to build and adaptations to the model are straightforward. The model would become more realistic when a probability distribution of the risk estimates and the probability distribution of disease introduction were included. The probability distributions could be based on the Confidence Intervals (CI) obtained from studies or based on estimates. In the deterministic model the costs of disease introduction were spread over a five-year period. In reality introduction of diseases will be a stochastic process. The year of outbreak will be a random event. However, a deterministic model is attractive as a tool to advice farmers. A deterministic model results in only one solution, which is easier to explain to farmers. A stochastic model needs many iterations to obtain the most likely solution, which is much harder to explain to farmers. With a deterministic model the uncertainty of the system can partly be shown with sensitivity analyses in which several scenarios are investigated (Dijkhuizen and Morris, 1997). A probabilistic or stochastic model would be more appropriate to determine the costs and benefits of a more closed farming system for the average Dutch dairy farm. However, the goal of the current model was to provide a simple tool to support farmers in their decisions on a more closed farming system, and the model meets this goal.

Management towards a more closed farming system includes mostly measures that do not influence the farming system as a whole too much. This assumption is a precondition for the use of partial budgeting. A disadvantage of partial budgeting is that no specific time pattern nor a high degree of uncertainty are involved in the method. A more closed farming system will be a permanent state and costs (e.g. depreciation) will return every year (see appendix). Because no random effects were included in the model all the costs, multiplied by the probability of introduction, were assumed to occur during the five-year period. The avoided losses due to introduction of infectious diseases will vary in reality over the years. Depending on the disease the losses will be highest in the year of outbreak (e.g. *L. hardjo*) or in the following years (e.g. BVDV). The avoided losses of introduction due to infectious diseases were more or less equally spread over the years because of the modelling approach. Cost-benefit analysis will only be useful to analyse management measures with higher initial costs and low-level benefits over a long period of time (Dijkhuizen and Morris, 1997). A more closed farming system will have moderate costs over a long period and the benefits are reasonably high. A cost-benefit analysis includes discounting of costs and benefits and might therefore lead to different conclusions about the profitability of a more closed farming system, particularly when diseases are introduced a long time after the management measures are taken (i.e. costs are made). In this case a more closed farm will become less profitable.

9.4.2 ORs versus RRs

In an economic model the RR is preferred over the OR since the RR is a direct estimate of the amount of disease prevented when a farm is not exposed. In contrast, the OR is an indirect measure; the odds of disease in the exposed group and the odds of disease in the unexposed group. Eliminating the risk of a factor in the economic model is therefore best represented by the RR. It is well known that ORs always overestimate the strength of the association. This is especially the case when the outcome is considered not rare, larger than 5% (Martin et al., 1987). The outcome variable; BHV1-positive or BHV1 introduction, was not infrequent in the studies from which the input of the economic model was derived (Van Schaik et al., 1998; 1999a; 2000a). The ORs were therefore expected to be overestimated. In the sensitivity analysis the ORs from Van Schaik et al. (1998) were corrected for this overestimation to derive an estimated RR (Beaudeau and Fourichon, 1998). The estimated RRs were considerably lower than the ORs. The benefit of a more closed farming system decreased with the lower RRs, but was still positive.

The method of Beaudeau and Fourichon (1998) must be restricted to cohort and cross-sectional studies, given the fact that the marginal frequencies of disease must be known to be able to use their proposed formula. The studies of Van Schaik et al. (1998; 1999a) were not true cross-sectional studies. The questionnaire was carried out at 214 selected dairy farms. The farms were selected on their BHV1 status. Based on the questionnaire only 107 farms remained for the analysis in Van Schaik et al. (1998). These farms had not vaccinated against BHV1. In the resulting group of 107 farms the proportion of cases and controls was similar to the proportion in the total population (Van Wuijckhuise et al., 1993). The RRs were therefore expected to be reasonable estimates. The disease status of the subgroups for the analyses in Van Schaik et al. (1999a; 2000a) were not representative for the Dutch population and the RRs could not be estimated from the ORs.

9.4.3 Validity of the results of the economic model

The economic calculations of the benefits of a more closed farming system were based on a Dutch situation. Other countries might have other diseases with different probabilities of introduction and other economic effects. Although the outcome of the economic model in this thesis will not be completely valid for any other dairy farm in any other country, it might be a good tool for a more educated view on a more closed farming system.

9.4.3.1 Risk factors

The mechanism of risk factors for introduction of BHV1 will be the same for any dairy farm. The magnitude of the risk factors for BHV1 in the model was such that direct animal contacts were more important than visitors were, which will be true for most infectious diseases in dairy cattle. The model might not cover all possible risk factors for introduction of BHV1, such as vermin, birds, dogs, et cetera. The risk of these factors for introduction of BHV1 was not known. A part of the effect of these unknown risk factors might be incorporated in "the distance to neighbouring cattle farms".

A more closed farming system will also prevent introduction of other infectious diseases. The direct animal contacts will be most risky for all infectious diseases as was shown in many studies. The inclusion criteria for infectious diseases in the model were that the losses of these diseases were well known, and, most importantly, it could be known by the farmer if his/her farm was free of those specific diseases. This was the main reason that e.g. Paratuberculosis could not easily be added to the model. Most farmers do not know the status of their farm for this disease.

The following studies show that infectious diseases have many risk factors in common. Trueman et al. (1996) and McDonough et al. (1999) found purchase of cattle and neighbourhood contacts to be risk factors for introduction of *S. dublin*. For *L. hardjo* Pritchard et al. (1989) report that risk factors for infection are, among others, purchase of cattle and a hired bull. Valle et al. (1999) found that purchase of animals, use of common pasture, and herd to herd contacts over pasture fences were risk factors for BVDV. The lengthy contacts (e.g. purchase) will be most risky followed by shorter contacts (e.g. over the fence). The ranking of the risk factors is not expected to differ much between diseases. The importance of professional visitors might slightly differ between diseases, depending on how long the viruses or bacteria survive outside the animal. The professional visitors might not be a risk factor for *L. hardjo*. Compared with BHV1, professional visitors might be more risky for transmission of *S. dublin*, which is a bacteria that can survive for a long time in manure. Furthermore, some risk factors that are not included in the model as risk factors for BHV1 need to be included when the model is going to be extended to *L. hardjo*, BVDV and *S. dublin*. Manure of other cattle farms will be a risk factor for *S. dublin*. Access to open water for drinking will be a risk factor for *L. hardjo* and *S. dublin*. Contact with sheep will be a risk factor for *L. hardjo* and BVDV. Rats and mice were found to be risk factors for spread of *S. dublin*.

9.4.3.2 Costs of management measures

The management measures to eliminate or reduce risk will be quite general for all dairy farms. The costs were solely based on the Dutch situation; a milk quota system, high milk prices, intensive production, high land prices, et cetera. This part of the model will be least valid for dairy farms in countries with a different system. However, this part of the model is also easiest to adapt since it was not based on an analytical study but on information more readily available (land prices, cattle prices, rearing costs, et cetera). The costs for the management measures were for one part based on information from KWIN-V (1999) and for the rest based on information from farmers and extension officers. The costs might differ between farms. The validation of the input showed that most farmers agreed with the cost as they were included in the model. The costs can be easily changed when a farmer does not agree. This flexibility of the model assures farm-specific calculations.

9.4.3.3 Reduction of risk

The reduction of risk due to management measures was arbitrarily chosen. It is clear that "no purchase" will reduce the risk of purchase to 0%. However, it is less clear how much the risk of professional visitors is reduced when the visitors use protective clothing instead of no measures. Previous studies of Van Schaik et al. (1998; 1999a; 2000a) gave an indication of the reduction in risk when professional visitors use protective clothing instead of no measures, but the exact amount is hard to quantify and is set to 60% risk reduction in the model. Information on the reduction of risk will be hard to obtain, if at all. The "success" of a management measure to reduce the risk will also depend on management quality, e.g. how consequent a farmer is. When protective farm clothing is not always used then the risk reduction of protective clothing will be smaller. The figures as used in the model can easily be adapted to suit an individual farmer. Further validation of the output of the model might also give an indication of how well the risk reduction represents reality.

9.4.3.4 Avoided losses

The costs of introduction of BHV1 were based on a study of Dutch dairy farms (Van Schaik et al. (1999b); Nooijen, 1998). The large variance in milk production losses in this study suggests that the magnitude of the effect of a BHV1 outbreak was dependent on other factors. These factors could not be derived from the study of Van Schaik et al. (1999b). Factors that might influence the losses were general resistance of the cattle, which might be related with stress, and the amount of contacts between cattle within the herd (Kaashoek et al., 1996). In comparable dairy production systems (e.g. in moderate climates) the short term, direct production losses of a BHV1 outbreak were expected to be quite similar on any dairy farm. The economic losses might however differ in other countries dependent on e.g. milk prices and cattle prices. The same will be true for the estimated losses of introduction of the other infectious diseases; BVDV, *L. hardjo*, and *S. dublin*. Losses as result of abortions or reduced growth were based on a study of Nooijen (1998) who administered a questionnaire on 38 certified BHV1-free dairy farms with a BHV1 outbreak. The exact loss of abortions or growth reduction could not be established in this study and needs further investigations.

9.4.3.5 Probability of introduction

The probability of introduction of infectious diseases used in the economic model was based on a group of Dutch farms that were free of several diseases and that had a fairly closed farming system (Van Schaik et al., 2000b). The probability of introduction on more open farms might be higher. A relatively closed farming system will become more beneficial when a farm is at risk for more diseases. An eradication program for an infectious disease will also enhance the benefits of a more closed farming system. The costs of introduction of such a disease will increase considerably because of the need to eradicate the disease of the farm in due time. On the other hand, an eradication program will decrease the probability of introduction of the disease when the national prevalence decreases. The economic model allows replacement of the probability of introduction and costs of BHV1, BVDV, *S. dublin* and *L. hardjo* and inclusion of other diseases. The four diseases that were included in the model at present should be seen as an indication of the costs of introduction of infectious diseases. The model will be most valid for farms that are already relatively closed and are at risk for BHV1, BVDV, *L. hardjo* and *S. dublin*. The economic benefits of a more closed farming system will be lower for farms that are less closed (i.e. they have to make high costs) or for farms that are not at risk for introduction of diseases (i.e. diseases do not exist or are already present at the farm).

9.5 Concluding remarks

The world market will have an increasing influence on dairy production. Countries can impose import restrictions for products of countries with a lower health status to protect their consumers or the health status of their cattle (Marabelli et al., 1999). The potential zoonotic threat of diseases such as *L. hardjo*, Paratuberculosis and *S. dublin* (Blackmore and Schollum, 1982; Bolin and Alt, 1989; Collins, 1994) will increase the need to eradicate such diseases.

Eradication programs for various diseases will increase the necessity for individual farmers to prevent introduction of diseases by a more closed farming system, which might in many cases be a profitable way to prevent economic losses due to infectious diseases. The economic model as described in this paper may be used as a tool to support individual farmers in their management decisions on the closeness of their farms and the related costs and benefits.

References

Beaudeau, F. and Fourichon, C., 1998. Estimating relative risk of disease from outputs of logistic regression when the disease is not rare. *Preventive Veterinary Medicine* 36: 243-256.

Bennett, R.M., 1993. Decision support models of leptospirosis in dairy herds. *The Veterinary Record* 132: 59-61.

Blackmore, D.K. and Schollum, L.M., 1982. Risk of contracting Leptospirosis on the dairy farm. *New Zealand medical journal* 95 (716): 649-652.

Bolin, C.A. and Alt, D.P., 1989. Clinical signs, diagnosis, and prevention of bovine leptospirosis. In: Caple, I.W. (ed) *Proceedings of the XX World Association for Buiatrics Congress*, Syndey, July 1998:899-904.

Collins, M.T., 1994. Paratuberculosis and Crohn's disease: A relationship? *Proceedings of the United States Animal Health Association*, 98:293-298.

Dijkhuizen, A.A and Morris, R.S., 1997. Animal Health Economics. Principles and applications. Post Graduate Foundation in Veterinary Science, Sydney and Wageningen Press, Wageningen.

Groenendaal, H., 1998. Simulation of the costs and benefits of a BVDV eradication program at dairy farms. MSc thesis, Wageningen University, The Netherlands, 67pp.

Jalvingh, A.W., 1992. The possible role of existing models in on-farm decision support in dairy cattle and swine production. *Livestock Production Science* 31: 351-365.

Kaashoek M.J., Straver, P.H., Van Rooy, E.M.A., Quak, J. and Van Oirschot J.T., 1996. Virulence, immunogenecity and reactivation of seven bovine herpesvirus 1.1 strains: Clinical and virological aspects. *The Veterinary Record* 139: 416-421.

KWIN-V 1998-1999. Quantitative information of animal production. Research station for cattle, sheep, and horse husbandry. Lelystad, The Netherlands, 416pp.

Law, A.M. and Kelton, W.D., 1991. Simulation modelling and analysis. Second edition. McGraw-Hill, Inc., Singapore, 759pp.

Marabelli, R., Ferri, G. and Bellini, S., 1999. Management of animal health emergencies: general principles and legal and international obligations. *Revue Scientifique et Technique* 18: 21-29.

Martin, S.W., Meek, A.H. and Willeberg, P., 1987. Veterinairy epidemiology. Principles and methods. Iowa State University Press, Ames, IA, 343 pp.

McDonough, P.L., Fogelman, D., Shin, S.J., Brunner, M.A. and Lein, D.L., 1999. Salmonella enterica serotype Dublin infection: on emerging infectious disease for the northeastern United States. *Journal of Clinical Microbiology* 37, 8: 2418-2427.

Nooijen, P.J.J.M., 1998. The economic losses of introduction of BHV1 by a decrease in milk, protein, and fat production at dairy farms. MSc thesis, Wageningen University, The Netherlands, 39pp. (in Dutch).

Pritchard, D.G., Allsup, T.N., Pennycott, T.W., Palmer, N.M.A., Woolley, J.C. and Richards, M.S., 1989. Analysis of risk factors for infection of cattle herds with *leptospira interrogans serovar hardjo*. In: Rowlands, G.J. (ed.), *Proceedings of a meeting of the Society for Veterinary Epidemiology and Preventive Medicine*. University of Exeter, 130-138.

Trueman, K.F., Thomas, R.J., MacKenzie, A.R., Eaves, L.E. and Duffy, P.F., 1996. *Salmonella Dublin* infection in Queensland dairy cattle. *Australian Veterinary Journal* 74, 5: 367-369.

Valle, P.S., Martin, S.W., Tremblay, R. and Bateman, K., 1999. Factors associated with being a bovine-virus diarrhea (BVD) seropositive dairy herd in the More and Romsdal County of Norway. *Preventive Veterinary Medicine* 11, 40(3-4): 165-177.

Van Schaik, G., Dijkhuizen, A.A., Huirne, R.B.M., Schukken, Y.H., Nielen, M. and Hage, J.J., 1998. Risk factors for existence of bovine herpesvirus 1 antibodies on nonvaccinating Dutch dairy farms. *Preventive Veterinary Medicine* 34: 125-136.

Van Schaik, G., Schukken, Y.H., Nielen, M., Dijkhuizen, A.A. and Huirne, R.B.M., 1999a. Application of survival analysis to identify management factors related to the rate of BHV1 seroconversions in a retrospective study of Dutch dairy farms. *Livestock Production Science* 60: 371-382.

Van Schaik, G., Shoukri, M., Martin, S.W., Schukken, Y.H., Nielen, M. and Dijkhuizen, A.A., 1999b. Modelling the effect of an outbreak of BHV1 on herd-level milk production on Dutch dairy farms. *Journal of Dairy Science* 82: 944-952.

Van Schaik, G., Schukken, Y.H., Dijkhuizen, A.A. and Benedictus, G. 2000a. Introduction of BHV1 at certified BHV1-free Dutch dairy farms. Submitted.

Van Schaik, G., Schukken, Y.H., Dijkhuizen, A.A., Barkema, H.W. and Benedictus, G. 2000b. Introduction of infectious diseases at Dutch SPF dairy farms: risk factors and economic consequences. Submitted.

Van Wuijckhuise, L., Bosch, J., Franken, P., Hage, J.J., Verhoeff, J. and Zimmer, G., 1993. The prevalence of Infectious Bovine Rhinotracheitis (IBR) in the Netherlands. In: Elbers, A.R.W. (ed), *Proc 6th meeting of the Dutch Soc for Vet Epidemiol Economics*. Boxtel:7-16.

Van Wuijckhuise, L., Bosch, J., Franken, P., De Wit, J., Frankena, K. and Elbers, A., 1997. Some epidemiological characteristics of bovine herpesvirus 1 (BHV1) infections as determined by bulkmilk testing of all Dutch dairy herds. *Epidemiologie et Sante Animale*, special issue; 31-32;11.13.1-3

Visser, S.C., Veling, J., Dijkhuizen, A.A. and Huirne, R.B.M. 1997. Economic losses due to *S. dublin* in dairy cattle. In: Kristensen, A.R. (ed), *Proceedings of Dutch / Danish symposium on animal health and management economics*. Copenhagen, January 1997, 143.

Vonk Noordegraaf, A., Buijtels, J.A.A.M., Dijkhuizen, A.A., Franken P., Stegeman, J.A. and Verhoeff, J., 1998. An epidemiological and economic simulation model to evaluate the spread and control of infectious bovine rhinotracheitis in the Netherlands. *Preventive Veterinary Medicine* 36: 219-238.

Appendix

The net revenue of some management measures to reduce or eliminate the risk of risk factors. All figures are in Dfl. and per event (i.e. purchase) or per year (i.e. grazing, visitors, temporary worker).

Risk factor: Purchase of a pregnant heifer

	Sub-optimal replacement of cow		Rearing of a extra heifer; not self supporting for forage		Testing a purchased heifer for BHV1	
Additional returns		0		0		0
Reduced costs		0	Purchase of a BHV1-free heifer	2000		0
Returns foregone		0		0		0
Extra costs	Retention Pay Off (RPO) of a replacement heifer	300	The value of a calve, milk, concentrates, forage, and other variable costs	2110	Visit of a veterinarian, blood sample and analysis	70
Net revenue per event		-300		-110		-70

Risk factor: Grazing cattle close to cattle from other farms

	Installing and maintaining a permanent double fence (1 ha.)	
Additional returns		0
Reduced costs		0
Returns foregone		0
Extra costs	Depreciation = 135, interest = 34, maintenance = 13	182
Net revenue per year		-182

Risk factor: Professional visitors

	Protective clothing and boots		Sanitary barrier [a]	
Additional returns		0		0
Reduced costs		0		0
Returns foregone		0		0
Extra costs	Three coveralls and three pairs of boots	297	Depreciation =253, interest =95, maintenance =38, protective clothing =297	683
Net revenue per year		-297		-683

[a] a simple sanitary barrier includes a disinfection basin for boots, bench, cupboard, protective clothing and boots, sink, heating, lights, and wall and floor coating.

Risk factor: Temporary worker

	Protective clothing and boots	
Additional returns		0
Reduced costs		0
Returns foregone		0
Extra costs	Coveralls and pair of boots	90
Net revenue per year		-90

General discussion

10.1 Why closed farming systems?

There are several reasons for forcing farms to prevent introduction of infectious diseases. The first one is the (world) market. When countries have a disease-free status they can restrict imports from countries with a lower health status and thus may expand their export as a result of their higher quality products (Marabelli et al., 1999). The second reason lies at country level. When a country decides to obtain a higher health status they can choose between voluntary and compulsory eradication programs. The third reason is that an individual farmer can decide to improve the health status of the herd to improve the economic results of the farm. Eradication of infectious diseases is facilitated by a more closed farming system. Introduction or reintroduction of infectious diseases is less likely when a farm is more closed, which will enhance the success of an eradication program (Vonk Noordegraaf et al., 1998).

In intensive animal production systems (such as in pigs and poultry) a closed farming system is more common practice than in dairy farming. As a result of disease outbreaks countries will restrict farmers in the number of contacts more and more. The CSF outbreak in the Netherlands in February 1997 resulted in stricter regulations. Pig farms are levied according to the number of contacts with other farms; the more closed, the less they have to pay (Horst et al., 1999). For dairy farms no such regulations exist yet. Dairy farming being a less intensive production system did not feel the need to prevent contacts as much as did the pig or poultry sector. However, this has changed in recent years. The margins in dairy farming have decreased and the economic losses due to infectious diseases are perceived to be larger. Furthermore, eradication programs for infectious diseases were implemented in the Netherlands as well as some other countries for Bovine Herpesvirus type 1 (BHV1), Bovine Virus Diarrhoea Virus (BVDV), Salmonella enterica subsp. enterica serotype Dublin (*S. dublin*), and Leptospira interrogans serovar hardjo (*L. hardjo*). The responsibility for eradication of infectious non-list A-diseases in the Netherlands is at farm level, implying that individual farmers are responsible for their animals' health. The increasing need to eradicate diseases and the shift of responsibility to individual farmers for healthy and disease free herds increased the importance of a more closed farming system. A definition for a more closed farming system is provided in Chapter 1.

The overall objective of the study was to obtain input for and construct a model to calculate the costs and benefits of a more closed system for dairy farms. First, the potential benefits and perception of farmers and their advisers of a more closed farm were investigated. The second and third objectives were to obtain input for the economic model and the last objective was to create a simplified economic model to calculate the costs and benefits of a more closed farming system. The model was developed to function as a tool to support farmers in their on-farm decisions about implementing a more closed farming system.

10.2 The potential of a more closed farming system

One way to convince farmers of the need to have a more closed farm is to show the economic consequences of such a system. Furthermore, farmers and their advisers need to agree on the definition of a closed farm. The first objective of this thesis was to investigate the potential net profit of more closed farms and the perception of farmers and their advisers about the most important factors to obtain a more closed farm.

10.2.1 Exploratory study of the benefits

An exploratory study was carried out to investigate whether there were economic benefits of a more closed farming system. This study is described in Chapter 2. The definition of a closed farm in Chapter 2 is different from the definition as used in this thesis (see Chapter 1). A "closed" farm in Chapter 2 is a farm that does not purchase cattle and does not rear cattle from or on other farms during a two-year period. The "closed" farms had a higher net profit of approximately Dfl. 70 per cow per year, which is approximately 5% of the typical net returns to labour and management of Dutch dairy farms. The definition of a "closed" farm in Chapter 2 was very limited and therefore extended in further investigations. More potential risk factors for introduction of infectious diseases were to be investigated and quantified. These risk factors needed to be recorded in time to correct for changes in the farmer's management. De Verdier Klingenberg et al. (1999) found improved technical results on a closed farm (i.e. no further contacts with cattle outside the herd was allowed) where BVDV was eradicated. However, the higher net profit found in Chapter 2 could not be explained by management or health status of "closed" farms. The results of the exploratory study were promising enough to start further investigation.

10.2.2 Perception of farmers and their advisers

In Chapter 3 a study was carried out to investigate the perception of farmers and some of their advisers (e.g., veterinarians and AI-technicians) concerning risk factors for introduction of BHV1 into Dutch dairy farms. To successfully implement a more closed system at a farm, there should be consensus among farmers and their advisers about what constitute the important risk factors for introduction of infectious diseases. The study in Chapter 3 showed that farmers and their advisers (especially veterinarians) had a different perception concerning risk factors for introduction of BHV1. Farmers considered their visitors important risk factors for introduction of BHV1 and farmers with a risky management, such as participation in cattle shows, did not perceive this management to be risky. Veterinarians did not consider visitors to be very important, but were more concerned about purchase of cattle. This thesis shows that both are right. Both direct animal contacts and professional visitors were found to be important risk factors for introduction of BHV1. Farmers and professional visitors should therefore be aware of the risk they take or embody and should not use each other as an excuse for not being cautious with respect to introduction of infectious diseases (e.g. purchase of cattle with an unknown disease status or entering a barn with clothing and boots that had already been used at other cattle farms). It can be concluded that more education is necessary about the risk factors for introduction of infectious diseases to gain support for a more closed farming system. The perception of risk factors was obtained by conjoint analysis, which proved to be a satisfying tool, in agreement with Horst et al. (1996). Perceptions of farmers and their advisers were quantified and could thus be compared. The results from the conjoint analysis can also facilitate discussion and education of farmers and their advisers.

10.3 Input for the economic model

The second and third objectives of the thesis were to quantify risk factors for introduction of BHV1, the losses due to introduction of BHV1, and the probability of introduction of infectious diseases. The results from Chapters 4, 5, 6, 7 and 8 could be used as input for the economic model described in Chapter 9.

10.3.1 Risk factors for introduction of BHV1

In Chapters 4 and 5 the risk factors for introduction of BHV1 into dairy farms were investigated. The data were collected in 1995 before the eradication of BHV1 started and farmers were often ignorant of the BHV1 status of their farm. Two methods of analysis, logistic regression and survival analysis were used to quantify risk factors. Interestingly, both methods resulted in similar risk factors for the presence of BHV1. The results of these analyses were used as input for an economic model. The risk factors found in this study were direct animal contacts (i.e. purchase and cattle shows), visitors and the distance to other cattle farms. The risk of direct animal contacts was expected, but the considerable risk of (professional) visitors was not. Providing protective farm clothing to visitors seemed to be an important protective factor against introduction of BHV1 into dairy farms.

In 1998 a compulsory eradication program for BHV1 was started, which made farmers aware of the BHV1 status of their farms. Farms that obtained a certified BHV1-free status were more likely to avoid introduction of BHV1 and were obliged to have a more closed farming system. In Chapter 6, data were collected on certified BHV1-free farms with and without an outbreak of BHV1. The risk factors for introduction of BHV1 into those farms were quantified with a stratified logistic regression and could be used to refine the economic model with some more risk factors. The study showed that farms, which had introduction of BHV1, were more likely to have cattle breach or escape and mingle with other cattle and were less likely to provide protective farm clothing to every professional visitor. Direct animal contacts such as purchase of cattle or participating in cattle shows, hardly occurred at certified BHV1-free farms and could therefore not be found risk factors.

In the three chapters different techniques and data sets were used to quantify the risk factors for the presence or introduction of BHV1. Survival analysis seemed to be the most powerful technique. The dependent variable yields more information, a continuous survival time instead of a binary outcome variable, and information on censored cases is included. Furthermore, the survival analysis is more like a longitudinal study and results in the incidence rates of seroconversion rather than in prevalence odds in logistic regression. However, the collection of data for survival analysis might be more difficult and costly than for logistic regression. Survival analysis is based on longitudinal data, while for logistic regression one observation is sufficient. From an analytical point of view survival analysis is a very valuable method, which may justify the costs.

In all three studies the use of protective clothing by professional visitors was found to be a protective factor, and although the form of contacts differed, direct animal contacts were also found to be important risk factors. This consistent finding indicates a true and important effect of direct animal contacts and a preventive effect of the use of protective farm clothing on introduction of BHV1.

10.3.2 Losses due to introduction of BHV1

Introduction of infectious diseases (e.g. BHV1, BVDV, *L. hardjo*, and *S. dublin*) into dairy farms can cause direct economic losses as a result of decreased technical results (Anderson and Blanchard, 1989; Bolin and Alt, 1998; Hage et al., 1998; Houe, 1999). Other economic losses that can occur are when the disease needs to be eradicated from a farm (e.g. in eradication programs) or when cattle with the disease have a lower value. In Chapter 7, a marginal model, a subject-specific random-effect model, and a transition model were developed to quantify the milk production losses caused by introduction of BHV1 at BHV1-free farms. The estimated milk production losses were used as input for the economic model and therefore a farm-specific estimate was preferred over a more general population average estimate. The farm-specific random-effect model also fitted the farms investigated best and resulted in the most precise estimate. The average economic losses due to decreased milk production were low (less than 1% of the net returns), but the variance was high. Some farms had little milk production losses while others had high production losses. These farms will also be more likely to have a clinical outbreak of abortions, reduced fertility and even deaths. Nooijen (1998) carried out a questionnaire on farms with a BHV1 outbreak and found that

50% of the farmers had seen signs of an infection, such as coughing and nasal discharge. On only 7-10% of the farms severe clinical signs were seen and cattle aborted or had to be culled due to secondary infections. Introduction of BHV1 into Danish BHV1-free farms resulted in (severe) clinical signs in 10-14% of the outbreaks (Nylin et al., 1998). Most economic losses due to a BHV1 outbreak at Dutch dairy farms are indirect losses caused by the compulsory eradication program; compulsory vaccination of all cattle twice a year, and in due time testing and culling of cattle to eradicate BHV1 again from the farm (Chapter 8).

10.3.3 Introduction of infectious diseases

BHV1 was the example disease in this thesis, since the eradication program in the Netherlands made data on BHV1 readily available. However, a more closed farming system will prevent introduction of more infectious diseases. In Chapter 8, the introduction of infectious diseases into dairy farms without those diseases was investigated. Ninety-three dairy farms, which were all free of BHV1 and almost all of *L. hardjo* participated in a cohort study to measure the probability of introduction of BHV1, BVDV, *L. hardjo* and *S. dublin*. The farms were more closed than other Dutch dairy farms. However, 13 of these farms experienced an introduction of one, and one farm two, of these diseases. The cause of introduction varied but were often direct animal contacts. The farms with introduction were also less disciplined with respect to provision of protective clothing to visitors. When farms have eliminated the risk of direct animal contacts, the next risk factor to focus on is the risk of professional visitors. A disciplined attitude in which protective farm clothing is always worn when entering the barn showed a decreasing risk of introduction of infectious diseases.

The study design was a cohort study at 95 Dutch dairy farms. This study design was chosen to verify the risk factors found by the case-control study (Chapter 4, and 5) and obtain more insight into management quality and changes in management with respect to introduction of diseases. Furthermore, the cohort study was meant to obtain estimates for the probability of introduction of infectious diseases into dairy farms. The number of farms in the study was a compromise between the optimal number of farms, time and money. The number of farms should have been larger to investigate the relatively rare event of introduction of diseases. On the other hand, farmers recorded data for the study and detailed management of the farmers was collected twice a year by farm visits, which limited the number of farms time- and money-wise.

Precise, consistent and detailed data on risk factors and management to reduce or eliminate the risk can only be obtained from farms by a relatively intensive follow-up. In an intensive follow-up farmers record data themselves and are visited regularly to avoid recall bias and retain interest of the farmers in the study. In the cohort study described in this thesis, visits at 6-monthly intervals were satisfactory. More visits are not expected to increase data quality much and would be too much of a burden for farmers and visitors. Fewer visits would lower the interest of the farmers for the research and data recording and decrease data quality considerably. Written questionnaires were not applicable either, farmers would also have lost interest and response would have been decreased. The response in the cohort study was almost 100%; only one farm left the study after one year, because the farmer ceased farming completely.

Not all farms were at risk for all diseases under investigation, because their complete disease status could not be known at the start of the study. The design resulted in very detailed data on management of the individual farms, but a fairly limited number of disease outbreaks. The analysis was restricted due to the lack of power, but still resulted in some sound and interesting results (Chapters 6 and 8).

In the future, a study in which both probability of introduction and detailed management collection are combined, might benefit of a different design. A solution for the lack of power will be to select a larger number of farms (at least 200) that are free of all diseases under investigation at the start of the study and follow them for a two-year period. A shorter period will not be useful because the probability of introduction will be too small; a longer period is not useful becausefarmers might not want to participate for such a long time and the probability of introduction might be very low into farms that had not have any outbreak in a two-year period. The collection of detailed management data will be very time-consuming on a larger number of farms for a two-year period. A solution to limit the number of farm visits might be to collect data on management at the start of the study and collect data again at a case farm and a (matched) control farm shortly after an introduction of a disease. This procedure is only useful when management data are collected shortly after an introduction so that recall bias is avoided. Introduction of diseases will, however, not always be detected fast, except when high expenses are made for a regular (monthly) sampling scheme.

Summarising, a longitudinal study such as a cohort study has several advantages compared with a case-control study namely, more information on disease incidence and production effects associated with a given exposure, no recall and minimal selection bias, accurate data, repeated measures on exposure are a possibility, and incidence rates can be estimated. The major disadvantages are, as mentioned in the discussion above, long-term and expensive, inefficient for rare diseases, and population attributable rates cannot be estimated.

10.4 The economics of a more closed farm

The last objective of the thesis was to develop an economic model to calculate costs and benefits of a more closed system to support on-farm decisions. The economic implications of a more closed farm will not always be obvious to a farmer and the economic model can provide better insight. In Chapter 8, a first attempt was made to calculate the benefits of a more closed farming system for the farms in the cohort study. The simplified partial budgeting showed that a more closed farm was economically profitable for specific situations only. However, a more elaborate model, which quantified the risk of certain management factors and which was more farm-specific was needed. Such a model is described and discussed in Chapter 9.

The economic model is a spreadsheet model, which is static and deterministic. The model can easily be adapted for different situations. The risk estimates, management measures, costs and probability of introduction of diseases can be changed to fit an individual farm. The model can serve as a tool to inform farmers about the costs and benefits of a more closed farm. However, in reality probability of introduction will be a stochastic process and the risk estimates of risk factors will have a probability distribution. Probabilistic models have, like deterministic models, one final solution and the outcome is therefore easier to interpret for farmers. A stochastic model needs many iterations and results in a most likely solution, which is much harder to explain to farmers. A probabilistic model will therefore be more appropriate for an on-farm decision support model, while a stochastic model would be more appropriate for a valid representation of the economic consequences of a more closed system for all Dutch dairy farms.

Several scenarios representing the situation of common dairy farms showed that a more closed farm is economically profitable in many cases. An important factor in the model was the amount of risk reduction resulting from certain measures. For example, how much risk was avoided when professional visitors used protective clothing. The most uncertain risk factor was grazing close to other cattle. It is obvious that the prevention of nose to nose contacts over the fence will reduce the risk. However, it is not known exactly how much distance is needed to reduce the risk of transmission completely. Mars (2000) estimated that the R_0 would be lower than 0.5 when the distance between unvaccinated animals was at least 6.2 metres. Measures to reduce the risk of grazing e.g. building a double fence can be very costly depending on the farm situation. This factor had a large influence on the profitability of a more closed farming system. For a favourably situated farm (e.g. not close to other cattle farms, plots separated from neighbouring cattle by wide ditches or wooded banks, et cetera) a more closed farming system will easily be profitable. However, when a farm is unfavourably situated, costs to reduce the risk of grazing can be very high and a more closed farming system will not easily be profitable.

In the Netherlands there is a development towards rearing less youngstock or farm youngstock at other, specialised farms. In this way the rearing costs of heifers are minimised to maximise farm income (Mourits, 2000). The financial difference of rearing one's own youngstock or purchasing will increase when labour, housing, fast increase in farm size, or the area of pasture are limited. For every farm the reason not to rear their own youngstock will differ. In the Netherlands, dairy farmers are advised to reduce the number of youngstock to avoid nutrient surpluses (Teenstra, 1997). In the US, for example, labour or fast growth of the herd size might constrain the rearing of one's own heifers. In the Netherlands, farmers generally raise more replacement heifers than are actually required for maintaining the dairy herd size. Excess heifers enable farmers to select better replacements and reduce the need to purchase cattle when extra milk production is needed. From an economic perspective, the number of youngstock reared should be limited. The increasing growth and intensification of dairy farms might even force farmers to stop rearing their own heifers completely. This can make dairy farms less closed. Farmers should be aware of the risk of introduction of diseases by purchasing heifers. Extra measures should be taken to reduce the risk, such as purchasing certified disease-free cattle, testing for diseases, and quarantine. The extra costs of those measures and the extra risk of introduction of infectious diseases should be included in the decision about the number of heifers to rear and whether to rear them at one's own farm.

10.5 Other results

10.5.1 Transmission of infectious diseases

During the study described in this thesis, numerous data were collected at the participating dairy farms. This thesis contains published papers based on a part of the data collected. However, several other studies were conducted to gain insight into the relations between management, the presence of infectious diseases and technical and economic results.
Van Alphen (1997) investigated whether the BHV1 status (positive or negative) or the closeness of 99 dairy farms influenced the economic results. Income from cattle sales was decreased at BHV1-positive farms, which might have been caused by a lower price for BHV1-positive cattle. BHV1-positive farms also had higher veterinary costs, but net profit nor milk production were lower compared to BHV1-negative farms. The closeness of dairy farms did not seem to influence technical or economic results, in contrast to the results in Chapter 2. However, the data used in Chapter 2 were much more uniform and of a higher quality.
Kamphuis and Enting (1997) determined whether the presence of infectious diseases (i.e. BVDV, *Paratuberculosis*, and *S. dublin*) was related to the closeness of dairy farms. The disease status and the closeness of the farms were obtained by a questionnaire, and were therefore more biased than the data obtained in Chapter 8. Farmers who said to have cattle infected with *Paratuberculosis* were more likely to apply manure from other cattle farms, to have a disinfection basin, to have a permanent worker, to have cattle breach or escape and mingle with other cattle, and to have an overcrowded barn for youngstock. Farmers who said

to have cattle infected with *S. dublin* were more likely to apply manure from other cattle farms. Farmers who said to have cattle infected with BVDV were more likely to participate with cattle in cattle shows and to have over the fence contacts with neighbouring cattle. The results of this study supported the necessity to gather objective data on the BVDV and *S. dublin* status of farms, which was done in the cohort study described in Chapter 8. The risk factors for introduction of BVDV found in Chapter 8 were comparable with those found by Kamphuis and Enting (1997). BVDV seemed to be introduced by direct animal contacts, i.e. purchase of cattle and over the fence contacts. The risk factor for introduction of *S. dublin* found in Chapter 8 was different, namely grazing cattle at other farms instead of applying manure from other cattle farms. Manure was not found to be a significant risk factor because only 1% of the farms in the cohort study applied manure from other farms.

Helmig and Van Vliet (1998) investigated the possible association between farm management and within farm transmission, technical results, and the status of the farms for BVDV and *S. Dublin*. The data on management and technical results were obtained by a questionnaire at the 95 dairy farms in the cohort study (Chapter 8). The disease status of these farms was known from blood and milk samples. They found that farms with BVDV carriers had an increased mortality of new-born calves and youngstock from 6 to 24 months old, and more cases of abortion. On farms with BVDV carriers youngstock came into contact with adult cattle more often. Houe (1999) mentioned the same potential losses due to BVDV. Contacts between youngstock and adult cattle is known to facilitate the spread of BVDV at dairy farms (Houe, 1999).

On the farms with *S. dublin* no effect on technical results could be found. However, farms with *S. dublin* supplied their calves with hay and concentrates at a later age and the person who fed the calves was more often the same person who milked the cows than someone who did not have contact with adult cows. These management factors were also mentioned by Visser et al. (1992). *S. Dublin* usually starts in adult cattle and spreads to the calves through manure. Therefore, contact of calves with manure of adult cattle should be avoided. A milker will be contaminated with manure from cows and might infect calves during feeding. The resistance of calves is better when concentrates and hay are provided at an early age.

The main conclusion of these studies was that management could reduce between and within farm transmission of BHV1, BVDV, *Paratuberculosis*, and *S. dublin* and that being free of these diseases could increase technical and economic farm results.

10.5.2 Management quality

Personal characteristics and skills of the farmer are often assumed to be important in explaining differences with respect to the success of a farm (Rougoor et al., 1998). Farmers who are well aware of risk factors and disciplined in their management were expected to be

less likely to have or introduce infectious diseases. Investigations to determine associations between management styles of farmers, risk attitude, actual management, disease status, and closeness of the farm were carried out, and some were found to be related.
Nooijen (1998) did not find an association between management and whether or not a BHV1 outbreak had a clinical course. Management styles and risk attitudes were not related to the BHV1 status (Fopma et al., 1996).
A questionnaire on risk attitude and management style was carried out at 68 dairy farms that participated in the cohort study (Chapter 8). The risk attitude of farmers was associated with some management measures related to treatment of diseased animals or preventive measures for udder health. However, no significant associations were found between farms with an outbreak of any disease and the risk attitude or management style. The only significant association (P=0.08) was that risk-averse farmers were less likely to have protective clothing for visitors. An association that was expected to be the opposite.
Management quality is expected to have a major influence on farm results, but some personal aspects are very difficult to measure. Drives and motivation, or abilities and skills, are very hard to detect and quantify and difficult to relate to actual management. Better results are expected from defining explicit actions related to the decision-making process (Rougoor et al., 1998). Chapters 6 and 8 an effort was made to measure management quality by collecting data on specific actions of farmers to obtain a more closed farming system, e.g. did farmers know the disease status of purchased cattle and were farmers aware of the disease status of neighbouring cattle. Unfortunately, the data were too sparse to analyse them properly and no relations between management quality and introduction of infectious diseases could be established. We expect that a successful closed farm that prevents introduction of infectious diseases depends more on the knowledge of the farmer about risk factors and correct measures to eliminate its risk (explicit actions) than on the risk attitude or management style of a farmer. Studying explicit actions to represent management quality related to a more closed farming system is expected to be more useful than studying management styles and risk attitudes of farmers.

10.6 Developments and future research

The world market will have an increasing influence on dairy production. Countries can impose import restrictions for products of countries with a lower health status to protect their consumers or the health status of their cattle (Marabelli et al., 1999). The potential zoonotic threat of diseases such as *L. hardjo*, Paratuberculosis and *S. dublin* (Blackmore and Schollum, 1982; Bolin and Alt, 1989; Collins, 1994) will even more increase the need to eradicate such diseases. The eradication of diseases will become the responsibility of the farmer. A way to increase the health status of the herd is to adopt a more closed farming system, which prevents introduction of infectious diseases. Some developments such as environmental regulations, higher land prices, decreasing margins, et cetera, might increase the costs of a more closed farming system. However, the need to eradicate diseases will increase the potential benefits of a more closed farming system, which are the avoided losses of introduction of infectious diseases.

An uncertain factor in the economic model is the amount of risk reduction of several management measures e.g. increasing the distance to other cattle while grazing, providing protective clothing for visitors, et cetera. Mars (2000) carried out studies to estimate the critical distance for transmission of BHV1, BVDV and BRSV. More studies need to be done to estimate air transmission of other diseases and estimate the critical distance in which air transmission is not possible. The importance of air transmission of diseases will influence the success of a more closed farming system. Farmers can adapt their management to eliminate the risk of direct animal contacts and of visitors. However, air transmission is difficult to avoid. Especially when it is not clear over what distance diseases can spread. Farmers can use air transmission as an excuse not to adopt a more closed farming system. The concept of a more closed farming system might gain acceptance of farmers when management measures to reduce the risk of air transmission are based on a critical distance for transmission. Further research is necessary to estimate the risk reduction of measures such as protective clothing, a sanitary barrier, preventing contact with cattle on cattle shows, quarantine and testing of purchased animals, et cetera. Although many studies were carried out on risk factors for introduction of infectious diseases, the cause of an introduction was still not always obvious. In almost 50% of the BHV1 introductions on BHV1-free farms (Chapter 6) there was no attributable cause. Furthermore, the causes of introduction of *S. dublin* on 7 dairy farms were not obvious either (Chapter 8). The probability of introduction of infectious diseases was estimated for a selected group of 95 dairy farms in the northern part of the Netherlands. A cohort study with a larger number of farms (at least 200-300) that are all free of several diseases and which are situated throughout the Netherlands might be necessary to obtain better information on the causes and probability of introduction of infectious diseases on Dutch dairy farms. A study longer than two years might not be useful, since farms that did not have an outbreak in those two years might be less likely to have an outbreak in the following years as a result of their closed farming system.

The costs of introduction of infectious diseases are hard to obtain from real cases. More studies are needed on the effect of introduction of infectious diseases on technical farm results. The losses in milk production were often the only effects that could be measured on case farms. However, the effect on fertility or abortions can also be much more costly. Proper fertility data are hard to obtain from case farms. However, for better estimates on losses of infectious diseases more effort might be worthwhile. Another interesting field for future research is the variability of losses at farms with a disease outbreak. Why do some BHV1-free farms have a clinical BHV1-outbreak and others a subclinical one. Part of the reason might be differences in virulence of BHV1 and another part can be the susceptibility of the cattle, which might be influenced by farm characteristics, e.g. the type of housing or the management of the farmer. The estimates of the benefits of a more closed farming system with an economic model will be more precise when the expected losses due to introduction of infectious diseases can be better predicted based on farm characteristics.

The present economic model can be improved by including risk, uncertainty, and random numbers, and thus making it a probabilistic or stochastic model. The advantage of a probabilistic model is that probability distributions of e.g. risk factors are incorporated and that the results are still easy to understand for farmers and suitable for on-farm decision support. A stochastic model will incorporate random number generators for e.g. the probability of introduction of diseases. The model needs many iterartions to obtain the most likely solution, which concept is harder to explain to farmers, but will be the best representation of the real world. However, the present deterministic model can already facilitate economic decisions about a more closed system at individual dairy farms.

10.7 Recommendations to farmers

10.7.1 Direct animal contacts

As mentioned in Chapter 1, numerous studies found direct animal contacts to be important risk factors for introduction of infectious diseases. The studies described in Chapters 4, 5, 6 and 8 confirmed the importance of direct animal contacts for introduction of BHV1, BVDV, *L. hardjo*, and *S. dublin*. In the study in 1995 before the BHV1 eradication program (Chapters 4 and 5), purchase of cattle, participation in cattle shows, and rejected cattle returning to the farm (rejected for e.g. export) were found risk factors for the presence of BHV1 at dairy farms. These risk factors were not found statistically significant for introduction of BHV1 at BHV1-free farms. Most importantly, to keep their BHV1-free status farms are obliged to purchase BHV1-free cattle only and may participate only in BHV1-free cattle shows, which reduces the risk of these factors considerably. Secondly, BHV1-free farms often encountered considerable (financial) efforts to eradicate BHV1 and therefore had or adopted a less risky management. The direct animal contact found significant for introduction of BHV1 on BHV1-free farms in Chapter 6, was when cattle breach or escape and mingle with other cattle. A farmer has less control of such a risk factor compared with e.g. purchase of cattle. The study described in Chapter 8 showed that farms with an introduction of BHV1, BVDV, *L. hardjo*

and *S. dublin* seemed to have direct animal contacts with other cattle more often due to purchase, over the fence contacts or grazing cattle at other farms.
One may conclude that direct animal contacts are still important risk factors for introduction of infectious diseases. Even though farmers can take extra measures, such as testing purchased animals for disease, this might not always be a sufficient measure; tests are not 100% sensitive and a disease might not be detectable yet. More attention should be paid to less obvious risk factors as over the fence contacts and cattle that breached or escaped. These risks can be avoided by having a sturdy fence with enough distance to prevent contact with neighbouring cattle. An even more certain method to reduce the risk would be to suspend grazing cattle when in an adjacent plot neighbouring cattle is grazing. The more distance between cattle, the less chance of infection with infectious diseases by air transmission or by direct contacts (Stärk, 1999; Mars, 2000). Pasture management should be adjusted so that grazing adjacent to neighbouring cattle is avoided, which would be facilitated when farmers cooperate with their neighbours.

10.7.2 Visitors

In all analyses on risk factors (Chapters 4, 5, 6 and 8) in this thesis the consistent use of protective clothing for professional visitors was found to be an important protective factor for introduction of infectious diseases. This repeated finding supports the hypothesis that visitors who handle cattle are able to introduce infectious diseases on a farm. Graat et al. (1998) found the same in poultry farms where the use of protective clothing by visitors was a significant protective factor for the presence of several *Eimeria* species. However, a part of the effect in the present thesis might also be explained by the management quality of farmers who are or are not consistent in providing protective clothing to visitors. A farmer who is consistent with protective clothing might also be more consistent with respect to other risk factors (e.g. make sure that cattle never has over the fence contacts with neighbouring cattle). If that is the case the effect of visitors will be overestimated in this thesis. Such correlations are very hard to obtain from farm data and are therefore difficult factors in multivariable models. The true risk of professional visitors can only be more precisely estimated by infection trials. Farmers and their visitors are advised to be consistent and always use protective farm clothing as they enter the barn until better information is available.
Protective boots are preferred over a disinfecting basin, since the disinfecting capacity of a basin is limited, especially when not properly used. Examples of improper use are contamination with organic material and wrong amount of disinfecting fluid. Washing hands before entering the barn might also be a measure to limit transmission of diseases, but was not investigated in this study. The difference between the protective value of a coverall or an overcoat is not known, but with respect to practical use an overcoat seems to be preferred.

The use of protective clothing has to be workable for a consistent use. Upon entering a farm, visitors should be notified of the need to use protective clothing and where to find it on the farm. When there is not a convenient place to change into protective clothing (i.e. outside the barn but in a covered area) exists at a farm, a farmer might consider building a sanitary barrier. Since very few farms in the study described in Chapter 8 had a sanitary barrier (i.e. 6 farms), the protective value of such a barrier could not be analysed. In pig and poultry production sanitary barriers are more common and their protective value is more generally acknowledged (Kuiper and Martens, 1994). A sanitary barrier on a dairy farm need not be of very elaborate and expensive structure (see Chapter 9). High expenses for a sanitary barrier are not yet supported by data. However, a sanitary barrier might support the consistent use of protective clothing and should be considered in future barn designs.

10.7.3 Transmission of BHV1 by other risk factors

Some studies found indications that air transmission was a risk factor for spread of BHV1 (Ackermann et al., 1990; Hage, 1997a; Nylin et al., 1998). Mars et al. (1999) showed clearly that BHV1 and BVDV could be transmitted by air from one barn to another over a short distance of 3.85 metres. Mars (2000) estimated that the probability of transmission of BHV1 was considerably lower when the distance between unvaccinated animals was at least 6.2 metres. In this thesis increased distance to other cattle farms was found to be a protective factor in relation to the presence of BHV1 at dairy farms. The closer a neighbour, the more likely contacts such as grazing cattle close to other cattle, neighbours entering each other's barn, et cetera. However, this risk factor might also incorporate air transmission. In the kind of studies described in this thesis, underlying factors (e.g. air transmission, vermin, companion animals, et cetera) were hard to investigate. The risk of these factors can be quantified in infection trials such as the one by Mars et al. (1999). The potential risk of sheep for spread of BHV1 was investigated by Hage et al. (1997b) and sheep were not capable of infecting bovines. In this thesis no proof was found for a potential risk of dogs, cats, birds, vermin and wildlife. Nor did the study find proof for transport vehicles to be risk factors for transmission of BHV1. The risk of these factors is expected to be limited, but more research needs to be done to justify this assumption.

In a two-year cohort study (Chapter 8) 13 of 95 farms experienced an outbreak of an infectious disease. This means that 82 farms were closed enough to prevent introduction of infectious diseases for at least two years. A more closed farming system in which the risky direct animal contacts are avoided and in which professional visitors consistently use protective clothing is sufficient to decrease the probability for introduction of infectious diseases considerably. A favourable farm situation in which the distance to neighbouring cattle is more than 6.2 metres might even decrease the probability towards zero. A more closed farming system can be a profitable basis to improve the health status of the herd and to eradicate infectious diseases.

10.7.4 In summary

For all infectious diseases:

1. Avoid direct animal contacts by all means;
- No purchase of cattle,
- No return of cattle once off the farm,
- No participation in cattle show,
- No escape of cattle to/from neighbours,
- No over the fence contacts with cattle,
- When direct animal contacts cannot be avoided, contacts should only be with cattle of the same or a higher disease status (e.g. purchase of cattle certified free of specific diseases).

2. Avoid visitors bringing in infections;
- Only relevant people in the barn,
- Provide protective farm clothing and boots to professional visitors.

Disease-specific measures:

3. Be aware of other risk factors that are more disease-specific;
- Manure of other cattle in dirty trucks or applied to own land,
- Ditch water that can be polluted with pathogens of other farms,
- Keep cattle as far away from neighbouring cattle as possible, and at least 6 metres,
- Avoid contact of cattle with other animal species, such as sheep, goats, rats and mice.

References

Ackermann, M., Müller, H.K., Bruckner, L. and Kihm, L., 1990. Eradication of infectious bovine rhinotracheitis in Switzerland: review and prospects. *Veterinary Microbiology* 23:365-370.

Anderson, M. and Blanchard, P., 1989. The clinical syndromes caused by Salmonella infection. *Veterinary Medicine* 84: 816-819.

Blackmore, D.K. and Schollum, L.M., 1982. Risk of contracting Leptospirosis on the dairy farm. *New Zealand Medical Journal* 95 (716): 649-652.

Bolin, C.A. and Alt, D.P. 1989. Clinical signs, diagnosis, and prevention of bovine leptospirosis. In: Caple, I.W. (ed) *Proceedings of the XX World Association for Buiatrics Congress*, Syndey, July 1998:899-904.

Collins, M.T., 1994. Paratuberculosis and Crohn's disease: A relationship? *Proceedings of the United States Animal Health Association*, 98:293-298.

De Verdier Klingenberg, K., Vagsholm, I. and Alenius, S.. 1999. Incidence of diarrhea among calves after strict closure and eradication of Bovine viral diarrhea virus infection in a dairy herd. *Journal of the American Veterinary Medicine Association* 214: 1824-1828.

Fopma, W., Jansen, S., and Vlaar, R., 1996. Risk factors for introduction of diseases into dairy farms. BSc thesis. Van Hall Institute, Leeuwarden, The Netherlands, 39 pp. (in Dutch).

Graat, E.A.M., Van der Kooij, E., Frankena, K., Henken, A.M., Smeets, J.F.M. and Hekerman, M.T.J., 1998. Quantifying risk factors of coccidiosis in broilers using data of a veterinary poultry practice. *Preventive Veterinary Medicine* 33(1-4): 297-308.

Hage, J.J., 1997a. Epidemiology of bovine herpesvirus 1 infections. PhD-thesis, Utrecht,

Hage, J.J., Vellema, P., Schukken, Y.H., Barkema, H.W., Rijsewijk, F.A., Van Oirschot, J.T. and Wentink, G.H., 1997b. Sheep do not have a major role in bovine herpesvirus 1 transmission. *Veterinary Microbiology* 57: 41-54.

Hage, J.J., Schukken, Y.H., Dijkstra, T., Barkema, H.W., van Valkengoed, P.H.R. and Wentink, G.H., 1998. Milk production and reproduction during a subclinical bovine herpesvirus 1 infection on a dairy farm. *Preventive Veterinary Medicine* 34:97-106.

Helmig, G. and Van Vliet, J., 1998. Risk factors and losses of BVD and *S. dublin* on dairy farms. BSc thesis. Van Hall Institute, Leeuwarden, The Netherlands, 39 pp. (in Dutch).

Horst, H.S., Dijkhuizen, A.A., Huirne, R.B.M. and De Leeuw, P.W., 1996. Introduction of contagious animal diseases into the Netherlands: Elicitation of experts opinions'. *Livestock Production Science* 53: 253-264.

Horst, H.S., Meuwissen, M.P.M., Smak, J.A. and Van der Meijs, C.C.J.M.., 1999. The involvement of the agriculture industry and government in animal disease emergencies and the funding of compensation in Western Europe. *Revue Scientifique et Technique* 18: 30-37.

Houe, H., 1999. Epidemiological features and economical importance of bovine virus diarrhea virus (BVDV) infections. *Veterinary Microbiology* 64: 89-107.

Jalvingh, A.W., 1992. The possible role of existing models in on-farm decision support in dairy cattle and swine production. *Livestock Production Science* 31: 351-365.

Kamphuis, E. and Enting, G., 1997. Closeness of dairy farms: The relations between risk factors and the presence of infectious diseases. BSc thesis, Van Hall Institute, Leeuwarden, The Netherlands, 36 pp. (in Dutch).

Kuiper, C.J. and Martens, M.R.T.M., 1994. Specific pathogen free health programs. *Tijdschrift voor Diergeneeskunde* 119: 390-393.

Marabelli, R., Ferri, G. and Bellini, S., 1999. Management of animal health emergencies: general principles and legal and international obligations. *Revue Scientifique et Technique* 18: 21-29.

Mars, M.H., Bruschke, C.J.M. and Van Oirschot, J.T., 1999. Airborne transmission of BHV1, BRSV, and BVDV among cattle is possible under experimental conditions. *Veterinary Microbioly* 66: 197-207.

Mars, M.H., 2000. Vaccinology and epidemiology of bovine herpesvirus 1 infections. Ph.D. thesis Utrecht University, Utrecht, 145 pp.

Mourits, M.C.M., 2000. Economic modelling to optimize dairy heifer management decisions. PhD-thesis, Wageningen University, The Netherlands, 149 pp.

Nooijen, P.J.J.M., 1998. The economic losses of introduction of BHV1 by a decrease in milk, protein, and fat production at dairy farms. MSc thesis, Wageningen University, The Netherlands, 39pp. (in Dutch).

Nylin, B., Madsen, K.G. and Ronsholt, L., 1998. Reintroduction of BHV 1 into Danish cattle herd during the period 1991-1995: A review of the investigations in the infected herds. *Acta Veterinaria Scandinavica* 39, 4, 401-413.

Rougoor, C.W., Trip, G., Huirne, R.B.M., and Renkema, J.A., 1998. How to define and study farmer's management capacity: Theory and use in agricultural economics. *Agricultural Economics* 18: 261-272.

Stärk, K.D.C., 1999. The role of infectious aerosols in disease transmission in pigs. *The Veterinary Journal* 158: 164-181.

Teenstra, E.D., 1997. To live and survive with MINAS: consequences of farm adjustments on surpluses, levies and income. PR-Report no. 168, Lelystad, The Netherlands (in Dutch with English summary).

Van Alphen, M., 1997. The influence of the IBR status and the closeness of dairy farms on economic results. MSc thesis, Wageningen University, Wageningen, The Netherlands, 32 pp. (in Dutch).

Visser, I.J.R., Veen, M., and Van der Giessen, J.W.B., 1992. *Salmonella dublin* infections in dairy cattle: A review. *Tijdschrift voor Diergeneeskunde* 117: 730-735.

Vonk Noordegraaf, A., Buijtels, J.A.A.M., Dijkhuizen, A.A., Franken, P., Stegeman, J. A. and Verhoeff, J., 1998. An epidemiological and economic simulation model to evaluate the spread and control of infectious bovine rhinotracheitis in the Netherlands. *Preventive Veterinary Medicine* 36: 219-238.

Summary

Introduction

The adoption of the Agreement on the Application of Sanitary and Phytosanitary measures (SPS agreement) of the World Trade Organisation (WTO) in 1994 has markedly changed the rules of international trade in animals and animal products. Governments are allowed trade restrictions based on health status to ensure food safety and animal health protection. Trade restrictions can be avoided by a high health status relative to other countries. In the European Union (EU) it was decided to set high standards and to follow a strategy of non-vaccination for most highly contagious animal diseases.

When countries decide to obtain a higher health status they can choose between voluntary and compulsory eradication programs. An individual farmer can also decide to improve the health status of the herd to improve the economic results of the farm. Eradication of infectious diseases is facilitated by a more closed farming system. Introduction or reintroduction of infectious diseases is less likely when a farm is more closed, which will enhance the success of an eradication program. For the Netherlands an important pathogen is Bovine Herpesvirus type 1 (BHV1). Several countries in the EU are free of this virus and hence they established import restrictions. BHV1 causes the disease called IBR as well as infectious pustular vulvovaginitis (IPV). A compulsory eradication program for BHV1 was started in the Netherlands in 1998.

The overall objective of the study was to obtain input for a model to calculate the costs and benefits of a more closed system for dairy farms. The input for the model was based on IBR, since there were numerous data on this disease. However, a more closed farming system may prevent introduction of other diseases as well. First, the potential benefits and perception of farmers and their advisers of a more closed farm were investigated. The second and third objectives were to obtain input for the economic model and the last objective was to create a simplified economic model to calculate the costs and benefits of a more closed farming system. The model was developed to function as a tool to support farmers in their on-farm decisions about implementing a more closed farming system.

The possibility of a more closed farming system

In Chapter 2, an exploratory study was carried out to investigate the technical and economic results of closed dairy farms. Farms that purchased cattle and/or shared pasture (defined as 'open' farms in this case) differ in technical results from farms that did not ('closed' farms). The results of the discriminant analysis showed that the 'closed' farms incurred lower costs for veterinary services, had a lower average age at first calving and a higher birth rate per 100 dairy cows. A linear regression analysis was carried out to investigate the influence of the farming system on economic farm performance. Being 'closed' was found to have a positive influence of Dfl 0.87 per 100 kg of milk on net profit, which equals about Dfl 70 per cow per year or 5% of the typical net return to labour and management.

Management measures for a more closed farming system will only be successfully applied if supported by farmers and their advisers (such as veterinarians). Therefore, the perception of farmers and advisers of the importance of various risk factors for introduction of diseases into a farm was determined in Chapter 3 by using Bovine Herpesvirus type 1 (BHV1) as an example.

As part of the study, an evening workshop was organised and run three times, in which in total, 49 farmers, veterinarians and AI technicians participated. The computerised questionnaire technique was based on Adaptive Conjoint Analysis (ACA). ACA has the advantage that participants can work with a large number of risk factors in a relatively short period of time. Another advantage of ACA (compared with standard questionnaires) is that the answers from each participant can be checked for consistency. Data from participants with inconsistent responses can be excluded from further analyses. The results of the ACA interview were compared with the risk factors reported in the literature to be associated with BHV1 status (e.g. purchase of cattle, participation in cattle shows) and with farmers' actual management to prevent introduction of diseases.

The workshop participants were all operating in the dairy sector and they seemed well aware of the risk of direct animal contacts for introduction of BHV1. Farmers thought visitors to be more risky than AI technicians and (especially) veterinarians. Farmers who purchased cattle or participated in cattle shows were of the opinion that the risks of direct animal contacts were more important than farmers who were not involved in those practices. Farms that were BHV1-positive (and participated in cattle shows more often) thought the risk of cattle shows smaller than BHV1-negative farms.

In summary, the Chapters 2 and 3 showed that the adoption of a more closed farming system seemed economically feasible, but the perception of farmers and their advisers as to risk factors was different. The importance of risk factors was determined in the next chapters.

Risk factors for introduction of BHV1

A more closed farming system may prevent introduction of infectious diseases on dairy farms and can be a good starting point for control of these diseases. In Chapters 4, 5 and 6 input for an economic model was obtained by quantifying the most important risk factors for introduction of BHV1. Data were available on the presence of BHV1 antibodies in bulk milk and/or blood samples of dairy farms. Furthermore, information about the possible risk factors for introduction of infectious diseases was collected by means of a questionnaire on 214 of

these dairy farms. The analyses described in Chapters 4 and 5 are based on data from this questionnaire.
A positive BHV1 status on 107 farms that had never vaccinated against BHV1 could only be caused by introduction of BHV1, and the analysis was based on those farms. Risk factors for introduction of BHV1 on the farms were quantified by using logistic regression. BHV1-positive farms purchased cattle and participated in cattle shows more often compared with BHV1-negative farms. A BHV1-positive farm also had more (professional) visitors in the barn that used protective farm clothing less often. The BHV1-positive farms were found to be situated closer to other cattle farms compared with the BHV1-negative farms.
In the analysis described in Chapter 4 the farms were classified as being BHV1-positive or negative. In Chapter 5 an analysis was carried out concerning a subgroup of farms, of which the prevalence of BHV1 was known. The prevalence of BHV1 at dairy farms is dependent on several factors. First, the prevalence is influenced by introduction of BHV1 into the farms, which is dependent on the risk factors for introduction. Second, the BHV1 prevalence might also be influenced by reactivation of BHV1 within the farm, which might be affected by the management of the farmer. In Chapter 5 the relations between risk factors, management factors and the estimated time since the latest BHV1 outbreak were investigated by means of Cox regression analysis. The results showed that direct animal contacts (i.e. purchase of cattle and returning export cattle) and occasional visitors increased the rate of BHV1 outbreaks on dairy farms. Management factors related to reactivation of BHV1 at dairy farms were all related to a loose housing system, which caused an increased risk of reactivation of BHV1 at the farm. The reactivation was facilitated when the barn was overcrowded (i.e. more cows than cubicles in the barn).
Survival analysis turned out to be a very efficient method compared with logistic regression. The results of the survival analysis are more like the relative risk of an incidence-based study, while the results from logistic regression (odds ratios) are prevalence based.
In May 1998 a compulsory eradication program for BHV1 started in the Netherlands. In December 1999 approximately 24% of the Dutch dairy farms were certified BHV1-free (Animal Health Service (AHS)). In Chapter 6, BHV1-free dairy farms with and without a BHV1 outbreak were compared. Ninety-three certified BHV1-free dairy farms participated in a cohort study that investigated the probability of introduction of infectious diseases. The probability of introduction of BHV1 was measured from the start of the study in March 1997 till the end of the study in April 1999. Ninety of these farms stayed BHV1-free and could be used as control farms. From January 1997 till March 1998 BHV1 was introduced into 44 BHV1-free dairy farms in the Netherlands (outbreak farms). Management data were collected on both cases and controls and the data sets (90 follow-up farms and 44 outbreak farms) were combined in one data set to be analysed together. For small data sets, and for data in which both small and large frequencies are expected in the contingency tables, the asymptotic

methods are unreliable. Our data set clearly resembled such a data set; the risk factors were rare events because the BHV1-free farms were closed farms on which little direct animal contacts occurred. Therefore, an exact stratified modelling approach was most suitable for the data. The outbreak farms were more likely to have cattle that breached or escaped and mingled with other cattle and less likely to provide protective clothing to professional visitors.
In summary, all studies showed that direct animal contacts and professional visitors were risk factors for introduction of BHV1. It was concluded that purchase of cattle, participating in cattle shows, allowing rejected export cattle to return to the farm, and having cattle breach or escape and mingle with other cattle were risk factors for introduction of BHV1. Furthermore, protective farm clothing for professional visitors was found to be an important protective factor for BHV1.

Milk production losses as a result of a BHV1 outbreak

The benefits of a more closed farming system are the avoided losses of introduction of infectious diseases. One of the impacts of disease is its effect on milk production. In order to estimate these effects repeated milk production records at regular intervals were used. In Chapter 7, the effect of an outbreak of BHV1 on herd level milk production of certified BHV1-free dairy farms was modelled. The objective was to study several linear models to quantify the effects of a BHV1 outbreak on milk production accounting for the repeated measures, and incorporating assumptions about the most likely duration of the effect of virus circulation.

A marginal model, a subject specific random effect model, and a transition model were developed. The effect of a BHV1 outbreak was statistically significant in the random effect model. This model fitted the farms investigated best and the results were most useful as input for the economic model for on-farm decision support. However, a transition model is a better model for generalising the results to the whole population of Dutch dairy farms.

The effect of a BHV1 outbreak on milk production derived from the random effect model amounted, on average, to a loss of 0.92 kg of milk per cow per day during the outbreak period of nine weeks. The milk production loss varied from almost none to 2 kg of milk per cow per day. This resulted in an average loss of Dfl 372 with a lower and upper confidence limit of Dfl 12 and Dfl 730 per BHV1 outbreak respectively on an average farm with 44 cows in milk.

Introduction of infectious diseases

The profitability of a more closed system will depend on the costs of the measures and on the potential losses due to introduction of diseases. In Chapter 8, the probability of introduction of infectious diseases and the possible causes were determined. Furthermore, the costs to prevent introduction were calculated. Ninety-five SPF dairy farms were selected from a database of BHV1-free farms for a cohort study on the possibilities of a more closed farming system to prevent introduction of BHV1, Bovine Virus Diarrhoea Virus (BVDV), Salmonella enterica subsp. enterica serotype Dublin (*S. dublin*), and Leptospira interrogans serovar hardjo (*L. hardjo*).

Although the SPF farms were already mainly closed, the probability of introduction of infectious diseases was fairly high, 14 introductions on 13 of the 95 farms. The study showed that the "non-outbreak" farms were significantly more closed than the "outbreak" farms. Direct animal contacts with other cattle should be avoided and professional visitors should be convinced of the necessity of putting on protective clothing before handling cattle. The economic calculations show that this will be profitable for an SPF farm. On average, the costs of the management measures were lower than the losses due to introduction of infectious diseases.

Economic model

In Chapter 9 the results of the previous chapters were incorporated into an economic model. The economic implications of a more closed farming system will not always been obvious to farmers. The management decisions need to be made for different parts of the farm and are dependent on the specific farm situation. A model to support these decisions was developed as a first attempt to model the economic consequences of a more closed farming system and a simple static deterministic design was chosen. The model was verified and partly validated and a sensitivity analysis was carried out to obtain insight into the model behaviour.

The input of the model was obtained from previous studies (Chapters 4, 5, 6, 7 and 8) that focused on introduction of BHV1. The risk factors in the model were therefore solely based on BHV1, but the losses due to introduction of other infectious diseases (i.e. BVDV, *L. hardjo*, and *S. dublin*) were added to the model. The management measures to reduce the probability of introduction of BHV1, the costs of these measures, and the risk reduction of these measures were obtained from other sources. Costs were calculated by using partial budgeting. A hypothetical farm was distinguished based on a survey of certified BHV1-free farms. The costs and benefits of a more closed system for this hypothetical farm were derived from the model.

The hypothetical 55-cow dairy farm that refrained from purchasing cattle, provided protective clothing to professional visitors and a temporary worker, and placed a double fence at six hectares of land to prevent over the fence contacts, had to spend Dfl. 899 per year, and Dfl. 4495 in five years. The probability of disease introduction was decreased by 74%. The avoided losses for disease introduction amounted to Dfl. 7033 over five years. The benefit of becoming more closed for this hypothetical farm was Dfl. 2538.

The sensitivity analysis showed that a more closed farming system was still beneficial when a sanitary barrier was used instead of just protective clothing, when the probability of introduction of infectious diseases was decreased, and when odds ratios in the model were replaced by more conservative relative risks. The benefits became negative when a farm had to place a double fence at 12 ha. instead of 6 ha., and when the probability of introduction of all diseases was decreased by 50%.
The economic model is a spreadsheet model, which is static and deterministic. The model could easily be adapted for different situations. The risk estimates, management measures, costs and probability of introduction of diseases could be changed to fit an individual farm. A probabilistic or stochastic model that includes risk and uncertainty would have been a better representation of the real world, but the deterministic model was already a satisfying tool to support on-farm decisions.

Discussion

Chapter 10 is an overall discussion of the thesis. The most important risk factors for introduction of infectious diseases are discussed and recommendations to obtain a more closed farm are given. The study design, a cohort study for a two-year period at 95 dairy farms (Chapter 8), is discussed and recommendations are given for a similar study in which the associations between probability of introduction and management are determined.
A large number of data were collected for this thesis, and used in several studies that are discussed in Chapter 10. These studies investigated within and between-farm transmission of infectious diseases and management quality.
The advantages and disadvantages of a deterministic economic model for on-farm decision support for a more closed system are discussed. The model can serve as a tool to inform farmers about the costs and benefits of a more closed farm. The consequences of an unfavourable situation of dairy farms close to neighbouring cattle and farm intensity for the profitability of a more closed system are discussed.
Future research should focus on the importance of air transmission for spread of infectious diseases, the risk reduction of measures such as protective clothing, the losses of introduction of infectious diseases and the variability of those losses between farms. Finally, the influence of certain developments (e.g. the world market, zoonotic threats of diseases, environmental measures, et cetera) on the profitability of a more closed farming system are discussed.

Main conclusions

- The implementation of a more closed system will be profitable for most farms that are at risk for several infectious diseases (i.e. BHV1, BVDV, *L. hardjo* and/or *S. dublin*). The profitability will increase when a farm is free of more diseases, but decrease when farms are limited in their facilities to rear replacement heifers or when a large amount of pasture adjoins pasture of other cattle farms with a lower disease status.

- The most important risk factors for introduction of BHV1 at a dairy farm were direct animal contacts and professional visitors. Protective clothing provided to professional visitors is an important preventive measure to reduce the risk of introduction of infectious diseases.
- Farmers are recommended to avoid all direct animal contacts, especially with cattle with a lower or unknown disease status. The number of visitors in the barn should be limited, and professional visitors should use protective clothing. Stress and an overcrowded barn should be avoided to minimise the chance of reactivation of BHV1.
- Farmers and veterinarians differ in their opinion about risk factors for introduction of BHV1; farmers perceived visitors to be more important than veterinarians did, and veterinarians perceived direct animal contacts to be more important than farmers did. However, both direct animal contacts and professional visitors are important risk factors for introduction of BHV1.
- In a subgroup of Dutch BHV1-free dairy farms that are also at risk for BVDV, *L. hardjo* and/or *S. dublin* and that are mainly closed, nine percent of the farms had one introduction per year of one of these four diseases. This is a rather high figure taking into account that these farms are more closed than the average Dutch dairy farm.
- An outbreak of BHV1 on a BHV1-free farm caused limited milk production losses of on average 39 kilograms per cow during the outbreak, but the variability between farms was high. The milk production losses at a farm varied from no losses to 77 kilograms of milk per cow per day during the outbreak.

The following conclusions can be drawn related to the methodologies used:

- A static, deterministic economic model is a satisfying tool to support on-farm decisions regarding a more closed system. However, an on-farm decision support model that includes risk and uncertainty is a better representation of the real world.
- Survival analysis is a very valuable method to quantify risk factors compared with logistic regression.
- A random effects model is most useful for the estimation of the effect of disease on milk production at a specific farm. A transition model is a better model to generalise the results to the whole population.
- Conjoint analysis resulted in objective and consistent data that enabled the comparison of the perception of farmers and their advisers about risk factors for introduction of BHV1.

Samenvatting

Inleiding

In 1994 heeft de World Trade Organisation (WTO) een overeenkomst gesloten genaamd 'Agreement on the Application of Sanitary and Phytosanitary measures (SPS agreement)'. Deze overeenkomst heeft een enorme invloed gehad op de wetgeving van de internationale handel in dieren en dierlijke producten. Regeringen mogen op basis van de eigen diergezondheidsstatus handelsbarrières instellen om de voedselveiligheid en de gezondheid van het eigen rundvee te beschermen. De handelsbarrières kunnen worden voorkomen door als land zelf een hoge gezondheidsstatus te hebben vergeleken met andere landen. De Europese Unie (EU) heeft besloten om tot een hogere diergezondheidsstatus te komen door een non-vaccinatie beleid voor de meeste besmettelijke dierziekten.
Landen die een hogere gezondheidsstatus willen verkrijgen kunnen kiezen tussen vrijwillige en verplichte bestrijdingsprogramma's voor veehouders. Individuele veehouders zullen de gezondheidsstatus van het rundvee willen verhogen om de economische resultaten van het bedrijf te verbeteren. Een meer gesloten bedrijf zal de kans op insleep of het opnieuw inslepen van infectieziekten verminderen, waardoor ziekten efficiënter kunnen worden bestreden. Bovine herpesvirus type 1 (BHV1) is een belangrijk virus in Nederland. Verschillende landen in de EU zijn al vrij van dit virus en ze kunnen daardoor import beperkingen opleggen aan andere landen, zoals Nederland. BHV1 veroorzaakt infectieuze bovine rhinotracheitis (IBR) en infectieuze pustular vulvovaginitis (IPV). In mei 1998 is in Nederland een verplicht bestrijding programma voor BHV1 van start gegaan.
Het doel van de studie was om gegevens te verkrijgen voor een model om de kosten en baten van een meer gesloten melkveebedrijf te berekenen. De gegevens voor het model zijn gebaseerd op IBR omdat er door het bestrijdingsprogramma veel gegevens van deze ziekte beschikbaar waren. Een meer gesloten bedrijf zal echter niet alleen insleep van IBR voorkomen, maar ook insleep van andere ziekten.
Als eerste is gekeken naar de mogelijke baten van een meer gesloten bedrijfssysteem en wat de veehouders en hun dierenartsen en inseminatoren belangrijke risicofactoren voor insleep van BHV1 vinden. Vervolgens zijn met een aantal analyses de risicofactoren voor insleep van BHV1 gekwantificeerd om ze in het model op te kunnen nemen. Tevens is de schade van insleep van BHV1 en de kans op insleep van een aantal andere infectieziekten bepaald. De gegevens zijn als invoer gebruikt om een eenvoudig economisch model te maken dat de kosten en baten van een meer gesloten bedrijfssysteem kan bepalen. Het model dient als hulpmiddel om de beslissingen van individuele veehouders over het implementeren van een meer gesloten bedrijfssysteem economisch te ondersteunen.

De mogelijkheden voor een meer gesloten bedrijfssysteem

In hoofdstuk 2 wordt een verkennende studie beschreven naar de technische en economische gevolgen van een meer gesloten systeem op melkveebedrijven. Bedrijven die rundvee aankochten en/of rundvee in of uitschaarden ('open' bedrijven) verschilden in technische resultaten van de bedrijven die dit niet deden ('gesloten' bedrijven). De discriminant analyse toonde aan dat de 'gesloten' bedrijven lagere dierenartskosten hadden, een lagere gemiddelde afkalfleeftijd hadden, en per 100 stuks melkvee werden er meer kalveren geboren in een jaar. Met een lineaire regressie analyse is onderzocht of het bedrijfssysteem invloed had op de economische bedrijfsresultaten. Op de 'gesloten' bedrijven was het saldo per 100 kg melk met 87 cent verhoogd, wat neerkomt op ongeveer 70 gulden per koe per jaar. Een bedrag van ongeveer vijf procent van de arbeidsopbrengsten van een bedrijf.
Een meer gesloten bedrijf kan succesvol zijn als veehouders en hun adviseurs, zoals een dierenarts het eens zijn over wat de belangrijkste risicofactoren voor insleep van ziekten zijn. In hoofdstuk 3 wordt een onderzoek beschreven naar wat veehouders, dierenartsen, en inseminatoren belangrijke risicofactoren voor insleep van IBR vinden. Hiervoor is er drie keer een avond georganiseerd waaraan in totaal 49 veehouders, dierenartsen, en inseminatoren hebben meegedaan. De deelnemers hebben een geautomatiseerde enquête gedaan die was gebaseerd op Adaptive Conjoint Analysis (ACA). ACA laat deelnemers steeds verschillende situaties beoordelen. De situaties die de deelnemers krijgen voorgelegd, worden door ACA bepaald aan de hand van voorafgaande antwoorden. Zodoende wordt een maximale hoeveelheid informatie verzameld met een beperkt aantal vragen. ACA heeft als voordeel dat de deelnemers snel met een groot aantal risicofactoren kunnen werken. Verder is het voordeel van ACA ten opzichte van een gewone enquête dat de antwoorden van elke deelnemer gecontroleerd kunnen worden op consistentie. Deelnemers die niet consistent hebben geantwoord kunnen worden verwijderd uit de dataset. De resultaten uit de ACA enquêtes zijn vergeleken met de risicofactoren zoals die in de literatuur worden gerapporteerd (bijvoorbeeld aankoop van vee, deelnemen aan keuringen, et cetera) en met het werkelijke management van de veehouders.
De deelnemers aan het onderzoek waren allen werkzaam in de melkvee sector en waren zich bewust van het risico van directe diercontacten voor insleep van BHV1. Veehouders vonden 'bezoekers' meer risicovol dan inseminatoren en (vooral) dierenartsen dat vonden. Veehouders die zelf rundvee aankochten of deelnamen aan keuringen vonden de risico's van directe diercontacten zelfs belangrijker dan veehouders die dit niet deden. Veehouders met een BHV1 positief bedrijf (bedrijven die ook vaker deelnamen aan keuringen) vonden het risico van veekeuringen kleiner dan BHV1 negatieve bedrijven.
Samenvattend werd in de hoofdstukken 2 en 3 aangetoond dat een meer gesloten bedrijf economische voordelen heeft, maar dat veehouders en hun adviseurs van mening verschillen

over wat belangrijker risicofactoren voor insleep van BHV1 zijn. In de volgende hoofdstukken zijn o.a. de risicofactoren voor insleep van BHV1 gekwantificeerd.

Risicofactoren voor insleep van BHV1

Een meer gesloten bedrijfssysteem kan insleep van infectie ziekten op melkveebedrijven voorkomen en de bestrijding van deze ziekten versnellen. In de hoofdstukken 4, 5 en 6 zijn de belangrijkste risicofactoren voor insleep van BHV1 gekwantificeerd. Deze risicofactoren zullen als input voor het economische model worden gebruikt. Op 214 melkveebedrijven zijn gegevens verzameld over de mogelijke risicofactoren voor insleep van infectieziekten met een enquête. De BHV1 status van deze bedrijven was bekend door maandelijkse tankmelkmonsters en/of door bloedmonsters van al het rundvee op het bedrijf. De analyse van deze dataset is beschreven in de hoofdstukken 4 en 5.
Honderdzeven van de 214 bedrijven hadden nooit gevaccineerd tegen BHV1 en de BHV1 positieve status van deze bedrijven kon dus alleen zijn veroorzaakt doordat BHV1 ooit het bedrijf is binnengekomen. De risicofactoren voor introductie van BHV1 op de bedrijven zijn gekwantificeerd met behulp van logistische regressie. De BHV1 positieve bedrijven kochten vaker rundvee aan en deden vaker mee aan veekeuringen vergeleken met de BHV1 negatieve bedrijven. Een BHV1 positief bedrijf had ook meer (professionele) bezoekers in de stal die minder vaak beschermende bedrijfskleding aan deden. Verder waren de BHV1 positieve bedrijven dichter gelegen bij andere melkveebedrijven vergeleken met de negatieve bedrijven. In hoofdstuk 4 was van bedrijven alleen bekend of ze BHV1 positief of negatief waren. In hoofdstuk 5 is een analyse gedaan met een subgroep van bedrijven waarvan de prevalentie van BHV1 op bedrijfsniveau bekend was door individuele bloedmonsters van het vee. De BHV1 prevalentie op melkveebedrijven is afhankelijk van een aantal factoren. Ten eerste wordt de prevalentie beïnvloed door insleep van BHV1 op het bedrijf, wat afhangt van de geslotenheid van het bedrijf. Ten tweede wordt de BHV1 prevalentie ook bepaald door reactivatie van BHV1 op een bedrijf, wat beïnvloed kan worden door het management van de veehouder. In hoofdstuk 5 is met behulp van Cox regressie analyse het verband onderzocht tussen risicofactoren, management factoren, en de geschatte tijd sinds de laatste IBR-uitbraak. Uit de resultaten blijkt dat directe diercontacten zoals aankoop van rundvee en het terugkrijgen van afgekeurd exportvee en niet-professionele bezoekers de kans op BHV1 uitbraken verhoogde. De managementfactoren die verband houden met reactivatie van BHV1 op melkveebedrijven hadden allemaal betrekking op het hebben van een ligboxenstal. De kans op reactivatie van BHV1 was hoger op bedrijven met een ligboxenstal. Verder werd de kans op reactivatie van BHV1 ook verhoogd door een overbezette stal (meer koeien dan ligplaatsen in de stal).

Survival analyse bleek een zeer efficiënte methode te zijn om risicofactoren te kwantificeren vergeleken met logistische regressie. De resultaten van de survival analyse zijn meer vergelijkbaar met de resultaten van een longitudinale studie dan met de resultaten van een prevalentie studie waarvoor logistische regressie vaak wordt gebruikt.
In mei 1998 is er in Nederland een verplicht bestrijdingsprogramma voor BHV1 van start gegaan. In december 1999 was ongeveer 24 procent van de Nederlandse melkveebedrijven gecertificeerd IBR-vrij (Gezondheidsdienst voor Dieren). In hoofdstuk 6 zijn IBR-vrije melkveebedrijven met en zonder IBR-uitbraak vergeleken. Drieënnegentig gecertificeerd IBR-vrije melkveebedrijven namen deel aan een cohort studie waarin de kans of insleep van infectieziekten werd onderzocht. Insleep van BHV1 werd bepaald vanaf het begin van de studie in maart 1997 tot aan het einde van de studie in april 1999. Op 90 van deze bedrijven werd geen IBR-uitbraak geconstateerd en deze bedrijven konden worden gebruikt als controle bedrijven. Van januari 1997 tot en met februari 1998 werd op 44 IBR-vrije melkveebedrijven in Nederland een IBR-uitbraak vastgesteld (uitbraak bedrijven). Op zowel de uitbraak als de controle bedrijven werden managementgegevens verzameld. Deze gegevens van het voorjaar 1997 tot het voorjaar van 1998 van 90 controle en 44 uitbraak bedrijven werden samengevoegd in één dataset en geanalyseerd. De asymptotische methoden zijn niet betrouwbaar voor een kleine dataset of voor gegevens waarin zowel kleine als grotere aantallen worden verwacht in de 2-bij-2 tabellen. Op de gecertificeerd IBR-vrije bedrijven in deze studie kwamen de risicofactoren voor insleep van ziekten zelden voor. De IBR-vrije bedrijven waren al zeer gesloten en directe diercontacten met niet IBR-vrij rundvee was niet toegestaan. Er is daarom gebruikt gemaakt van een exacte gestratificeerde analyse methode. Uit de analyses bleek dat de bedrijven met een IBR-uitbraak vaker rundvee hadden dat uitbrak uit de wei en in contact kwam met ander vee. Verder werd er op bedrijven met een IBR-uitbraak minder vaak beschermende bedrijfskleding aan professionele bezoekers verstrekt.
Samenvattend bleek uit alle studies dat directe diercontacten en professionele bezoekers risicofactoren waren voor insleep van BHV1. Er kan worden geconcludeerd dat aankoop van vee, deelname aan veekeuringen, afgekeurd exportvee terugkrijgen op het bedrijf, en het hebben van rundvee dat uitbreekt en in contact komt met ander rundvee belangrijke risicofactoren voor insleep van BHV1 zijn. Verder is gevonden dat bedrijfskleding voor professionele bezoekers een belangrijke beschermende factor is om insleep van BHV1 te voorkomen.

Daling van de melkproductie door een IBR-uitbraak

De baten van een meer gesloten bedrijfssysteem zijn gelijk aan de niet optredende schade als gevolg van insleep van infectieziekten op een bedrijf. Eén van de schadelijke gevolgen van insleep van ziekten kan een daling in de melkproductie zijn. Om deze schade te kunnen schatten is gebruik gemaakt van historische melkcontrolegegevens van bedrijven. In hoofdstuk 7 wordt het effect beschreven van een uitbraak van BHV1 op de melkproductie van gecertificeerd IBR-vrije melkveebedrijven. Het doel van de studie was om verschillende lineaire modellen te vergelijken en het effect van een IBR-uitbraak op de melkproductie te kwantificeren, daarbij corrigerend voor de herhaalde waarnemingen. Verder is er een aanname gedaan over de meest waarschijnlijke periode waarin het virus op een bedrijf circuleert.

Er is een marginaal model, een bedrijfsspecifiek random effect model, en een transitie model ontwikkeld. De melkproductiedaling als gevolg van een IBR-uitbraak was statistisch significant in het random effect model. In dit model werd de variantie van de onderzochte bedrijven het beste verklaard en de resultaten waren het meest geschikt voor het economische beslissingsondersteunende model. De resultaten uit het transitie model zouden meer algemeen geldig zijn geweest voor de totale populatie van gecertificeerd IBR-vrije melkveebedrijven in Nederland en waren daardoor minder geschikt voor het bedrijfsspecifieke model.

De gemiddelde melkproductiedaling als gevolg van een IBR-uitbraak bedroeg 0,92 kg melk per koe per dag en dat gedurende een periode van negen weken waarin het virus op het bedrijf circuleerde. De melkproductiedaling varieerde van een verwaarloosbare hoeveelheid tot 2 kg melk per koe per dag. De gemiddelde economische schade van een uitbraak bedroeg 372 gulden met een ondergrens en bovengrens van respectievelijk 12 gulden en 730 gulden per IBR-uitbraak op een gemiddeld bedrijf met 44 melkkoeien.

Insleep van infectieziekten

Het economische voordeel van een meer gesloten bedrijf hangt af van de kosten van de maatregelen en van de mogelijke schade van insleep van ziekten die wordt voorkomen. In hoofdstuk 8 is bepaald hoe vaak infectieziekten op bedrijven werden in gesleept en wat de mogelijke oorzaken waren. Verder is berekend wat de mogelijke kosten zijn van maatregelen om insleep van ziekten te voorkomen. Er is een cohort studie gedaan naar de mogelijkheden van een meer gesloten bedrijfssysteem om insleep van BHV1, Bovine Virus Diarree Virus (BVDV), Salmonella enterica subsp. enterica serotype Dublin (*S. dublin*), en Leptospira interrogans serovar hardjo (*L. hardjo*) te voorkomen. De deelnemers waren IBR-vrije bedrijven die in de meeste gevallen ook vrij waren van de andere ziekten.

Hoewel de bedrijven al redelijk gesloten waren, werd er toch op een aantal bedrijven een ziekte ingesleept. Op 13 van de 95 bedrijven werd één ziekte en op één bedrijf werden 2 ziekten ingesleept. Het onderzoek toonde aan dat de 'niet-uitbraak' bedrijven significant meer gesloten waren dan de 'uitbraak' bedrijven. Om insleep van ziekten te voorkomen dient een bedrijf directe diercontacten te voorkomen en professionele bezoekers dienen bedrijfskleding aan te doen voor zij de stal betreden. De economische berekeningen lieten zien dat, gemiddeld genomen, de kosten voor maatregelen om meer gesloten te worden lager waren dan de kosten van insleep van infectieziekten.

Het economisch model

In hoofdstuk 9 zijn de resultaten uit de voorafgaande hoofdstukken gecombineerd in een economisch model. Het is lastig voor veehouders om de economische consequenties van een meer gesloten bedrijfssysteem te overzien. Er dienen bedrijfsspecifieke beslissingen te worden genomen voor verschillende onderdelen van het bedrijf. Het model dat in hoofdstuk 9 wordt beschreven is een eerste poging om de economische gevolgen van een meer gesloten bedrijfssysteem te beschrijven. Het model kan beslissingen van individuele veehouders over een meer gesloten bedrijfssysteem economisch ondersteunen. Het model is statisch en deterministisch en het is geverifieerd en gedeeltelijk gevalideerd. Met een gevoeligheidsanalyse is het gedrag van het model bepaald.

Het model is opgebouwd met gegevens verkregen in de studies beschreven in de hoofdstukken 4, 5, 6, 7 en 8. Deze hoofdstukken waren voornamelijk gericht op insleep van BHV1 en het risico van de factoren in het model betreft daarom alleen insleep van BHV1. Een meer gesloten bedrijfssysteem voorkomt echter ook insleep van andere ziekten en daarom zijn de kosten van insleep van BVDV, *L. hardjo*, en *S. dublin* aan het model toegevoegd. De maatregelen om de kans op insleep van BHV1 (en andere ziekten) te beperken, de kosten om die maatregelen te nemen, en de effectiviteit van deze maatregelen om het risico te beperken zijn uit andere bronnen verkregen. De kosten zijn berekend op jaarbasis met behulp van partial budgetting. Uit gegevens van IBR-vrije bedrijven is een hypothetische bedrijf samengesteld waarvan de kosten en baten van een meer gesloten systeem zijn berekend met het economische model.

Het hypothetische melkveebedrijf heeft 55 melkkoeien en verandert het management als volgt: het koopt geen rundvee meer aan, laat professionele bezoekers en een tijdelijke medewerker bedrijfskleding aantrekken en plaatst een dubbele afrastering op zes hectare land om over-de-draad contact met ander rundvee te voorkomen. De kosten voor dit nieuwe management bedroegen 899 gulden per jaar en 4495 gulden in vijf jaar. De kans op insleep van ziekten was afgenomen met 74 procent. De schade van insleep van ziekten die daarmee werd voorkomen bedroeg 7033 gulden in vijf jaar tijd. De baten van een meer gesloten bedrijfssysteem voor dit hypothetische bedrijf bedroegen in vijf jaar in totaal 2538 gulden.

De gevoeligheidsanalyse toonde aan dat een meer gesloten bedrijfssysteem nog steeds rendabel was als er een hygiëne sluis werd geplaatst in plaats van uitsluitend bedrijfskleding voor bezoekers. Het meer gesloten bedrijfssysteem was ook rendabel als de kans op insleep van infectieziekten een stuk lager was en wanneer de odds ratios (OR) in het model werden vervangen door lagere relatieve risico's (RR). Een bedrijfssysteem was niet meer rendabel

wanneer het bedrijf een dubbele afrastering op 12 hectare land in plaats van op 6 hectare zou zetten, of wanneer de kans op insleep van alle ziekten 50 procent lager was.
Het economische model is een statisch en deterministisch spreadsheet model dat eenvoudig aangepast kan worden. De risico's, maatregelen, kosten en kans op insleep van ziekten kunnen worden aangepast voor een specifieke bedrijf. Een probabilistisch of stochastisch model waarin risico en onzekerheid zijn opgenomen zou beter overeenkomen met de werkelijkheid. Het huidige deterministische model is echter ook al een goed hulpmiddel om beslissingen over een meer gesloten systeem voor individuele melkveebedrijven te ondersteunen.

Discussie

Het laatste hoofdstuk 10 is de algemene discussie van het proefschrift. De belangrijkste risicofactoren voor insleep van infectieziekten worden bediscussieerd en er worden aanbevelingen gedaan aan veehouders voor een meer gesloten bedrijfssysteem. De opzet van de studie, een 2-jarige cohort studie op 95 melkveebedrijven) wordt besproken. Er worden aanbevelingen gedaan voor een gelijksoortige studie waarin de verbanden worden onderzocht tussen de kansen op insleep van ziekten en het management.
Voor het onderzoek in dit proefschrift zijn een grote hoeveelheid gegevens verzameld en deze gegevens zijn gebruikt in verschillende studies die worden besproken in hoofdstuk 10. Deze studies waren met name gericht op de binnen en tussen bedrijf transmissie van infectieziekten en op de kwaliteit van het management van veehouders.
De voordelen en nadelen van een deterministisch economisch model voor het ondersteunen van beslissingen omtrent een meer gesloten bedrijfssysteem worden besproken. Het model kan als hulpmiddel dienen om veehouders te informeren over de kosten en baten van een meer gesloten bedrijf. De gevolgen van een ongunstige ligging van melkveebedrijven dichtbij ander rundvee met een lagere ziektestatus en de intensiteit van een bedrijf voor de rentabiliteit van een meer gesloten systeem worden besproken.
Toekomstig onderzoek zou zich moeten richten op het belang van transmissie van ziekten door de lucht, de mate waarin maatregelen zoals bedrijfskleding het risico van insleep reduceert, de kosten van insleep van infectieziekten en de grote variatie in deze kosten tussen bedrijven. Tenslotte worden een aantal ontwikkelingen op bijvoorbeeld de wereldmarkt en op milieugebied besproken die de rentabiliteit van een meer gesloten bedrijfssysteem mogelijk beïnvloeden.

Aanbevelingen voor veehouders

Voor alle infectieziekten geldt:

1. Voorkom alle directe diercontacten met ander vee;
- geen aankoop van rundvee,
- geen rundvee op het bedrijf terugnemen als het van het bedrijf af is geweest (bijvoorbeeld afgekeurd export-vee),
- geen deelname aan veekeuringen,
- voorkomen dat rundvee uitbreekt en in contact komt met ander rundvee,
- geen over-de-draad contacten met ander rundvee,
- als directe diercontacten niet kunnen worden voorkomen dan alleen contacten met rundvee van een zelfde of hogere ziektestatus (bijvoorbeeld aankoop van gecertificeerd ziektevrij vee).

2. Voorkomen dat bezoekers ziektekiemen op het bedrijf binnen brengen;
- laat alleen mensen in de stal toe waarvan het noodzakelijk is,
- laat bezoekers die in aanraking komen met rundvee beschermende bedrijfskleding en laarzen aantrekken vóór het betreden van de stal.

Voor specifieke infectieziekten geldt:

3. Pas op voor risicofactoren die meer ziekte-specifiek zijn;
- mest van andere rundvee bedrijven in veewagens of op het eigen land (*S. dublin, Paratuberculose*),
- slootwater dat besmet kan zijn met de ziektekiemen van andere bedrijven (*S. dublin, Paratuberculose, L. hardjo*),
- houd rundvee zover mogelijk gescheiden van ander rundvee en ten minste zes meter (BHV1, BVDV),
- voorkom contact van rundvee met andere diersoorten, zoals schapen (BVDV), geiten (*Paratuberculose)*, ratten en muizen (*S. dublin*).

De belangrijkste conclusies

- Voor de meeste bedrijven die vrij zijn van een aantal infectieziekten zoals BHV1, BVDV, *L. hardjo* en/of *S. dublin* zal een meer gesloten bedrijfssysteem rendabel zijn. De rentabiliteit zal toenemen wanneer het bedrijf vrij is van meer ziekten, maar afnemen wanneer de bedrijfssituatie beperkend is voor de opfok van voldoende jongvee of wanneer het bedrijf een ongunstige ligging heeft waardoor er veel land grenst aan land van een ander rundveebedrijf met een lagere ziektestatus.

- De belangrijkste risicofactoren voor insleep van BHV1 op een melkveebedrijf zijn directe diercontacten en professionele bezoekers. Bedrijfskleding is een belangrijke beschermende maatregel om het risico van insleep van ziekten te verminderen.
- Veehouders dienen alle directe diercontacten met ander rundvee te voorkomen met name met rundvee met een lagere of onbekende ziektestatus. Het aantal bezoekers in de stal dient zo klein mogelijk te worden gehouden en professionele bezoekers die in aanraking komen met rundvee dienen voor het betreden van de stal bedrijfskleding aan te trekken. Om de kans op reactivatie van BHV1 zo klein mogelijk te houden dienen stress en een overbezette stal te worden voorkomen.
- Veehouders en dierenartsen verschillen van mening over wat de belangrijke risicofactoren voor insleep van BHV1 zijn. Veehouders vinden het risico van bezoekers groter dan dierenartsen dat vinden en dierenartsen vinden directe diercontacten een groter risico dan veehouders dat vinden. Zowel directe diercontacten als professionele bezoekers zijn echter belangrijker risicofactoren voor insleep van BHV1.
- Negen procent van de Nederlandse IBR-vrije melkveebedrijven die ook vrij zijn van BVDV, *L. hardjo* en *S. dublin* hebben één insleep per jaar van één van deze vier ziekten. Dit is een aanzienlijk percentage als in aanmerking wordt genomen dat de onderzochte bedrijven reeds meer gesloten waren dan een gemiddeld Nederlands bedrijf.
- Een IBR-uitbraak op een IBR-vrij bedrijf veroorzaakt gemiddeld genomen slechts een kleine daling in de melkproductie van 39 kilo per koe gedurende de uitbraak, maar er is veel variatie tussen bedrijven. De melkproductiedaling op een bedrijf varieerde aanzienlijk, namelijk van een verwaarloosbare hoeveelheid tot 77 kg melk per koe gedurende de uitbraak.

De volgende conclusies hebben betrekking op de gebruikte technieken:

- Een statisch deterministisch economisch model is een goed hulpmiddel ter ondersteuning van beslissingen over maatregelen om insleep van ziekten op een melkvee bedrijf te voorkomen. Een beslissingsondersteunend model waarin risico en onzekerheid worden meegenomen is echter een betere weergave van de werkelijkheid.
- Survival analyse is een waardevolle methode vergeleken met logistische regressie om risicofactoren te kwantificeren.
- Een random effect model is het beste model om het effect van een ziekte op de melkproductie van een specifiek bedrijf te bepalen. Een transitie model is een betere model als de resultaten algemeen geldend moeten zijn voor een hele populatie.

- Conjoint analyse resulteerde in objectieve en consistente gegevens. De gegevens konden gebruikt worden om een vergelijking te maken tussen de perceptie van veehouders en hun adviseurs over de risicofactoren voor insleep van BHV1.

Related publications

Scientific papers

Van Schaik, G., Dijkhuizen, A.A., Huirne, R.B.M., en Benedictus, G., 1998. Insleep van IBR op melkveebedrijven; De beoordeling van de risico's van veehouders en dierenartsen. *Tijdschrift voor Diergeneeskunde,*maart 15, 6, 123, 180-183.

Van Schaik, G., Dijkhuizen, A.A., Benedictus, G., Barkema, H.W., and Koole, J.L., 1998. Exploratory study on the economic consequences of a closed farming system on Dutch dairy farms. *The Veterinary Record,* March 7, 240-242.

Van Schaik, G., Dijkhuizen, A.A., Huirne, R.B.M., Schukken, Y.H., Nielen, M., and Hage, J.J., 1998. Risk factors for excistence of BHV1 antibodies on non-vaccinating Dutch dairy farms. *Preventive Veterinary Medicine,* 34,125-136.

Van Schaik, G., Dijkhuizen, A.A., Huirne, R.B.M., and Benedictus, G., 1998. Adaptive Conjoint Analysis to determine the perceived risk factor of farmers, veterinarians and AI technicians for introduction of BHV1 to dairy farms. *Preventive Veterinary Medicine,* 36, 101-112.

Van Schaik, G., Schukken, Y.H., Nielen, M., Dijkhuizen, A.A., and Huirne, R.B.M., 1999. Application of survival analysis to identify management factors related to the rate of BHV1 seroconversions in a retrospective study of Dutch dairy farms. *Livestock Production Science,* 60, 371-382.

Van Schaik, G., Shoukri, M., Martin, S.W., Schukken, Y.H., Nielen, M., and Dijkhuizen, A.A. 1999. Modelling the effect of an outbreak of BHV1 on herd-level milk production on Dutch dairy farms. *Journal of Dairy Science* 82, 944-952.

Conference papers

Van Schaik, G., Dijkhuizen, A.A., Huirne, R.B.M. and Benedictus, G., 1996. A more closed farming system on dairy farms to reduce disease introduction, In: Graat, E.A.M. and Frankena, K. (Eds) *Proceedings of the annual meeting of the Dutch society for Veterinary Epidemiology and Economics (VEEC)*, Wageningen, 11 December 1996: 37-43.

Van Schaik, G., Dijkhuizen, A.A., Huirne, R.B.M., Nielen, M., and Benedictus G., 1997. Risk analysis and economic consequences of a more or less closed farming system on Dutch dairy farms, In: Anders Ringgaard Kristensen (eds.), *Proceedings of the Dutch/Danish Symposium on Animal Health and Management Economics*, Copenhagen, 23-24 January 1997, Dina Notat No. 56: 129-139.

Van Schaik, G., Dijkhuizen, A.A., Huirne, R.B.M, Nielen, M., and Benedictus, G., 1997. The potential of a more closed system on dairy farms to improve the animal health status and economic results. *Proceedings of the symposium of the International Society for Veterinary Epidemiology and Economics*, Paris, 8-11 July 1997: 10.10.1-3.

Van Schaik, G., Dijkhuizen, A.A., Huirne, R.B.M., Schukken, Y.H., and Benedictus, G., 1997. Management and economic results associated with the BHV1 status of dairy farms. *Proceedings of the 9th International Congress in Animal Hygiene*, Helsinki, 17-21 August 1997: 591-594.

Van Schaik, G., Dijkhuizen, A.A., Nielen, M., Schukken, Y.H., and Martin, S.W., 1998. A more closed farming system to prevent introduction and spread of BHV1 between and within dairy farms. In: Caple, I.W. (Ed.), *Proceedings of the 20th World Association for Buiatrics Congress,* Sydney, 6-10 July 1998, 729-734.

Conference abstracts

Van Schaik, G., Shoukri, M., Martin, S.W., Schukken, Y.H., Nielen, M., and Dijkhuizen, A.A., 1998. Modeling the effect of an outbreak of BHV1 on milk production. In: Wensing, Th.(Ed.), P*roceedings of the 10th International Conference on Production Diseases in Farm Animals.* Utrecht, 24-28 August 1998, p.257.

Van Schaik, G., Schukken, Y.H., Nielen, M., Dijkhuizen, A.A., and Huirne, R.B.M., 1999. Application of survival analysis to identify management factors related to the rate of BHV1 seroconversions at Dutch dairy farms. In: Arendonk, J.A.M. (Ed.), Book of abstracts of the 50th annual meeting of the European association for animal production. Zurich, 22-26 August 1999, p.121.

Courses

Van Schaik, G., Dijkhuizen, A.A., Huirne, R.B.M., en Benedictus, G., 1997. Risico-analyse en economisch rendement van een meer of minder gesloten bedrijfsvoering op melkvee bedrijven. PHLO-cursus 'Diergezondheidszorg in economisch perspectief', Wageningen, 26-28 maart, 11 pp.

Van Schaik, G., Dijkhuizen, A.A., Schukken, Y.H., en Benedictus, G., 1998. Analyse van risicofactoren voor binnen en tussen bedrijfstransmissie van BHV1 op melkveebedrijven. PAOD-cursus 'De bedrijfsdiergeneeskundige aanpak van infectieziekten op rundvee bedrijven deel 2', Drachten, 12-14 mei, Deventer, 1-3 december, pp. 14-26.

Van Schaik, G., en Nielen, M., 1998. Gesloten of verantwoord open?! Cursusmap Satellietproject Diergezondheid, derde bijeenkomst.

Non-scientific publications

Harcksen, P., 1997. De grenzen van het 'bewust open bedrijf'. *Diergezondheid in Beweging; De Nieuwsbrief* 8.

Hogenkamp, W., 1998. Uitbraak IBR kost ruim *f*3000. *Boerderij/Veehouderij* 83 ,18, p. 1.

Hovenga, M., 1997. Honderd bedrijven nemen deel aan onderzoek naar gesloten bedrijfsvoering. *Het Landbouwblad*, 7 juni 1997.

Van Schaik, G., Dijkhuizen, A.A., Benedictus, G., Barkema, H.W., en Koole, J.L., 1996. Gesloten bedrijf lijkt te lonen. *Veeteelt*, augustus 2, 926-928.

Van Schaik, G., Dijkhuizen, A.A., Huirne, R.B.M., en Hage, J.J., 1997. Status scheidt stallen. Het risico van insleep van IBR op melkveebedrijven. *Veeteelt*, maart 2, 314 -316.

Van Schaik, G., Dijkhuizen, A.A., Huirne, R.B.M., en Benedictus, G., 1998. Insleep IBR op melkveebedrijven; De visie van veehouders, dierenartsen en inseminatoren over de risico's. *Veeteelt*, februari 2, 184-186.

Van Schaik, G., Nielen, M., Dijkhuizen, A.A., en Hage, J.J., 1998. Vrij en toch IBR-uitbraak. Praktijkonderzoek naar daling melkproductie na IBR-uitbraak op gecertificeerde bedrijven. *Veeteelt*, september 1, 1008-1010.

Zevenbergen, G., 1996. Meer bezoek op IBR-vrije bedrijven. *Oogst* 8, p. 33.

Zevenbergen, G., 1997. Gesloten bedrijf, een hele klus maar wel nodig. Oogstplus voor de veehouderij, bijlage *Oogst* 28, 16-17.

Dankwoord

Begin 1995 kwam Geert Benedictus van de Gezondheidsdienst voor Dieren met de vraag of de leerstoelgroep Agrarische Bedrijfseconomie kon berekenen wat de economische gevolgen van een meer gesloten bedrijfsvoering waren. Een gesloten bedrijf was in die tijd voor veehouders nog een 'vies' begrip. Gelukkig is het toch 'gesloten bedrijf' gebleven in plaats van een 'risico-mijdend bedrijf', 'preventieve bedrijfsvoering' of een 'verantwoord open bedrijf', het had mijn proefschrift nog dikker gemaakt. In april 1995 kon ik met een voorstudie beginnen waaruit bleek dat een meer gesloten bedrijfssysteem rendabel was. Genoeg reden om financiering te gaan zoeken voor een promotieonderzoek. In november 1995 kon ik met het eerste jaar van mijn onderzoek beginnen, en eind 1996 was ook de financiering voor de resterende drie jaar rond. Nu, vijf jaar later is de term 'gesloten bedrijf' een min of meer door melkveehouders geaccepteerd begrip. Ik hoop dat mijn onderzoek daar toe heeft mogen bijdragen en dat de acceptatie wordt omgezet in actie en leidt tot meer gesloten bedrijven.
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Gerdien

Curriculum Vitea

Gerdineke (Gerdien) van Schaik werd op 28 januari 1971 geboren te Zwolle. In 1989 behaalde zij haar VWO-diploma op de Thorbecke Scholengemeenschap te Zwolle. In september van dat jaar is zij gestart met de studie Zoötechniek aan de Landbouwuniversiteit te Wageningen. In juni 1995 sloot ze deze studie af met een afstudeervak Veehouderij voor de Gezondheidsdienst voor Dieren te Gouda en twee afstudeervakken Agrarische Bedrijfseconomie, bij de Gezondheidsdienst voor Dieren te Drachten en bij het International Livestock Research Institute, Nairobi, Kenia. Een stage voor Veehouderij werd uitgevoerd bij de Dairy Research Corporation te Hamilton, Nieuw Zeeland. Vanaf april 1995 werkte zij bij de leerstoelgroep Agrarische Bedrijfseconomie o.a. aan een voorstudie naar gesloten bedrijven voor de Gezondheidsdienst voor Dieren. Vanaf november 1995 tot augustus 2000 heeft zij als toegevoegd onderzoeker bij de leerstoelgroep Agrarische Bedrijfseconomie aan haar promotieonderzoek gewerkt, hetgeen geleid heeft tot dit proefschrift. Het onderzoek is gefinancierd door de Gezondheidsdienst voor Dieren, het Ministerie van Landbouw, Natuurbeheer en Visserij, en CR-Delta. Een deel van het onderzoek is uitgevoerd bij het Department of Population Medicine, Ontario Veterinary College, University of Guelph, Canada en bij het Department of Population Medicine and Diagnostic Sciences, College of Veterinary Medicine, Cornell University, USA.

Vanaf augustus 2000 zal Gerdien van Schaik gedurende twee jaar gaan werken als Postdoc voor het Department of Population Medicine and Diagnostic Sciences, Cornell University, USA aan een onderzoek getiteld "Point estimation and variability in prevalence in herds with low disease prevalence using imperfect test: *M. Paratuberculosis* prevalence in the Netherlands and New York state."